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Water Supply of Indian Wells Valley, California

by
Pierre St.-Amand
Consultant to the NWC Technical Director

APRIL 1986

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FOREWORD

This report documents a recent evaluation of the water supply of Indian Wells Valley, Calif. The report traces the historical development of the Valley's water supply, evaluates the Valley's current water supply, projects the Valley's future water supply based on current water use, and recommends measures for conserving water and for developing additional water sources.

This report has been prepared primarily for the timely presentation of information. Although care has been taken in the preparation of the technical material presented, conclusions drawn are not necessarily final and may be subject to revision. This report represents one of at least two major theories of ground-water hydrology for the Indian Wells Valley. This report is released for information only and does not necessarily reflect the views of the Naval Weapons Center.

This report has been reviewed for technical accuracy by W. R. Moyle, United States Geological Survey, and Professor Stanley N. Davis, Department of Hydrology, University of Arizona.

AD-A171814

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION	1b RESTRICTIVE MARKINGS
UNCLASSIFIED	
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT
	Approved for public release; distribution
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	is unlimited

4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
NWC TP 6404	

6a NAME OF PERFORMING ORGANIZATION	6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION
Naval Weapons Center		

6c ADDRESS (City, State, and ZIP Code)	7b ADDRESS (City, State, and ZIP Code)
China Lake, CA 93555-6001	

8a NAME OF FUNDING/SPONSORING ORGANIZATION	8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Naval Weapons Center		

8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT NO
China Lake, CA 93555-6001				

11 TITLE (Include Security Classification)

WATER SUPPLY OF INDIAN WELLS VALLEY, CALIFORNIA

12 PERSONAL AUTHOR(S)
St.-Amand, Pierre

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Summary	FROM 1950 TO 1985	1986 April	71

16 SUPPLEMENTARY NOTATION

17	COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Water Naval Weapons Center
			Hydrology Ridgecrest
			Indian Wells Valley China Lake

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

(U) The water supply of Indian Wells Valley is finite. Water pumpage and consumptive water use exceeds the natural recharge to the Valley's ground-water supply. In 1984 28,000 acre-feet of water was pumped from the aquifer. This figure represents annual water pumpage increases of 9% above the natural recharge.

(U) Domestic wells south and east of the Ridgecrest area are becoming contaminated with poor quality water. This water is flowing into the Ridgecrest area because concentrated pumping is lowering the water table. If the present pumping pattern is continued, saline water from the China Lake playa will migrate into the heavily pumped area in the Ridgecrest and Intermediate Well Fields and will shorten the useful life of the water supply.

(U) Currently there is no water crisis. If, however, water is not conserved or alternate water sources developed, only 10 to 20 years' worth of useful water remains in the ground-water budget.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION	
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	UNCLASSIFIED	
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code)	22c OFFICE SYMBOL
Pierre St.-Amand	619-939-3104	NWC Code 013

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

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EXECUTIVE SUMMARY

The water supply of Indian Wells Valley comes from precipitation in the Sierra Nevada and the Argus and Coso Ranges. The total recharge to the system is estimated to be 11,000 acre-feet per year. Before 1920, this same amount of water was lost by evapotranspiration from the China Lake playa.

The safe perennial yield of the Indian Wells Valley is 10,000 acre-feet per year, provided that evapotranspiration in the playa area can be reduced to 1,000 acre-feet per year or less. If more water is used, it must come from the naturally stored underground water.

About 2,200,000 acre-feet of useful water are stored in the basin. Of this, only about 600,000 acre-feet are available under the present pumping pattern before the aquifer is contaminated with saline water from the playa.

In 1979 22,600 acre-feet of water were pumped into the valley. Of this total, 3,100 acre-feet went to Searles Valley, 3,400 went to the Indian Wells Water District, 5,000 went to the Naval Weapons Center, and the remainder went to small water companies, domestic wells, and agriculture. In 1979 the overdraft, the amount of water removed in excess of recharge, was about 14,000 acre-feet. In 1979 the consumptive water use was 26,500 acre-feet; in 1984, consumptive use was 28,000 acre-feet.

Water in the various clay bodies and at depth in parts of the valley is saline. The salinity increases with depth. Domestic wells south and east of the Ridgecrest area are rapidly becoming contaminated by poor quality water. This water is flowing into the area because concentrated pumping is lowering the water table. In addition to well contamination, other wells are drying up. If the present water pumping pattern is continued, saline water from the China Lake playa could migrate into the heavily pumped areas in the Ridgecrest and Intermediate Well Fields and will shorten the useful life of the water supply.

The seepage of poor quality water into the upper aquifer from the sewer ponds will eventually force poor quality saline water associated with the China Lake playa into the Ridgecrest area. About 1,600 acre-feet of industrially reusable water are lost from the sewage ponds each year. This water could be used as plant process water in Trona.

It is not known how much of Indian Wells Valley's water recharge comes from the Coso and Argus Ranges. Water from these ranges is potentially available for capture and use. At present the water is probably all lost to evaporation. The Coso Basin and the Argus Range should be explored for water resources.

Contraction of desiccated clays is causing distortion of the surface in parts of Ridgecrest and Inyokern.

The pumping pattern of the Indian Wells Valley's major water users should be consolidated and changed. It is suggested that a series of wells, spaced each half mile, be drilled along a north-south line beginning east of the railroad tracks at Inyokern and extending northward at least to the Louisiania Pacific Corporation sawmill. The wells should be pumped carefully to develop a uniform and constant drawdown. The ownership and operation of domestic wells and small water companies should be continued; this will result in a smoother water level decline over larger areas because the pumping is spread out. The total cost to the valley will be less than if long pipelines are used to deliver water to individual users in outlying areas. The less concentrated pumping will systematically capture the evaporative discharge and will considerably decrease the rate of drawdown and the rate of obsolescence of privately owned wells.

Water use in the valley should be limited to about 10,000 acre-feet a year. This quantity is adequate for the present population of 30,000 people provided some care is taken. Of this 10,000 acre-feet per year, 3,000 acre-feet, at least, will have to go to Searles Valley, unless industrially reusable water is exported. This leaves 7,000 acre-feet for local consumption. The 10,000 acre-feet per year will support a population of 90,000 people, in perpetuity, provided that some care is taken to conserve and reuse water and to capture all the discharge.

At present there is no water crisis. Enough water is available to support a much larger population than that of the Searles and Indian Wells Valleys. However, some changes in water management are absolutely necessary to ensure best water use; although these changes will cost more, they will ensure an adequate water supply for an increased population.

Possible sources of additional water are Rose Valley or the southern Owens Valley; and Chimney Creek or the South Fork of the Kern River, during years of plentiful water. Desalinization of saline water would create another possible minor water source. Of these sources, only importation from Chimney Creek or from the South Fork of the Kern River holds any serious promise. A study of these resources should be made soon in order to have water available before it is needed. Indian Wells Valley can get by nicely on current resources and still continue to grow in population and economy if water is conserved and used wisely. If we do neither, or if we do not develop alternatives, 10 to 20 years' worth of useful water remains in our present resources.

INTRODUCTION

Indian Wells Valley is a delightful place to live and to work. The same good weather and easily available water that contributed to the selection of the Valley as the home of the Naval Weapons Center (NWC) have also attracted many folk who wish to retire in an unhurried, rural atmosphere. However, the same fine weather that is on the one hand so attractive, on the other hand imposes a severe limitation on Valley activities. Sunny weather usually means little rain–and indeed we have little. Our well water, the only water we have, comes from rain and from water flowing into the Valley from nearby hills and mountains.

The Valley is a closed container with limited space beneath the Valley floor to hold water, and not all of this water is good. No alternative sources of water are readily available, so we must rely at this time on our ground water supply. The more we know about our ground-water supply, the more sensibly we can plan for the management of this resource.

Please do not misunderstand the contents of this report. We do not yet have a water crisis. However, some of our current water-management practices are not well adapted to our Valley's hydrology. I will point out the limits of current practices and suggest some modifications that will enable us to adapt our demands to nature's ability to provide water. Although our current usage exceeds ground-water replenishment, creative water management could support three times the present population in perpetuity.

A water supply is like a bank account: so much flows in, so much is taken out, and the rest remains. If you wish to stay within the account, you must know what you have and what you use. If you withdraw more than is deposited, you will eventually go broke. You need a budget. So it is with a water supply.

To prepare a water budget, we must have particular information about our water supply: how it gets into the Valley, how it is stored, and how it is withdrawn. It is the purpose of this report to provide such information.

An Annotated Bibliography, a Supplemental Bibliography, and a Glossary are included at the back of the report for reader reference.

GEOGRAPHY OF INDIAN WELLS VALLEY

Indian Wells Valley is a roughly rectangular, 480 square mile, enclosed basin (Figure 1 and Photo 1). It extends about 35 miles in a north south direction and 25 miles in an east west direction. The Sierra Nevada bounds the Valley on the west, the Coso Range on the north, the Argus Mountains on the east, and the Rademacher Hills and El Paso Mountains on the south.

The hills surrounding Indian Wells Valley reach elevations of nearly 9,000 feet. The elevation of the Valley itself ranges from about 3,000 feet at the edges to a low of 2,152 feet on China Lake playa.

Indian Wells Valley is a southern extension of Rose Springs Valley, itself a southern extension of Owens Valley. Rose Valley and Indian Wells Valley are connected by a narrow gap at Little Lake, the lowest point on the surface of Rose Valley.
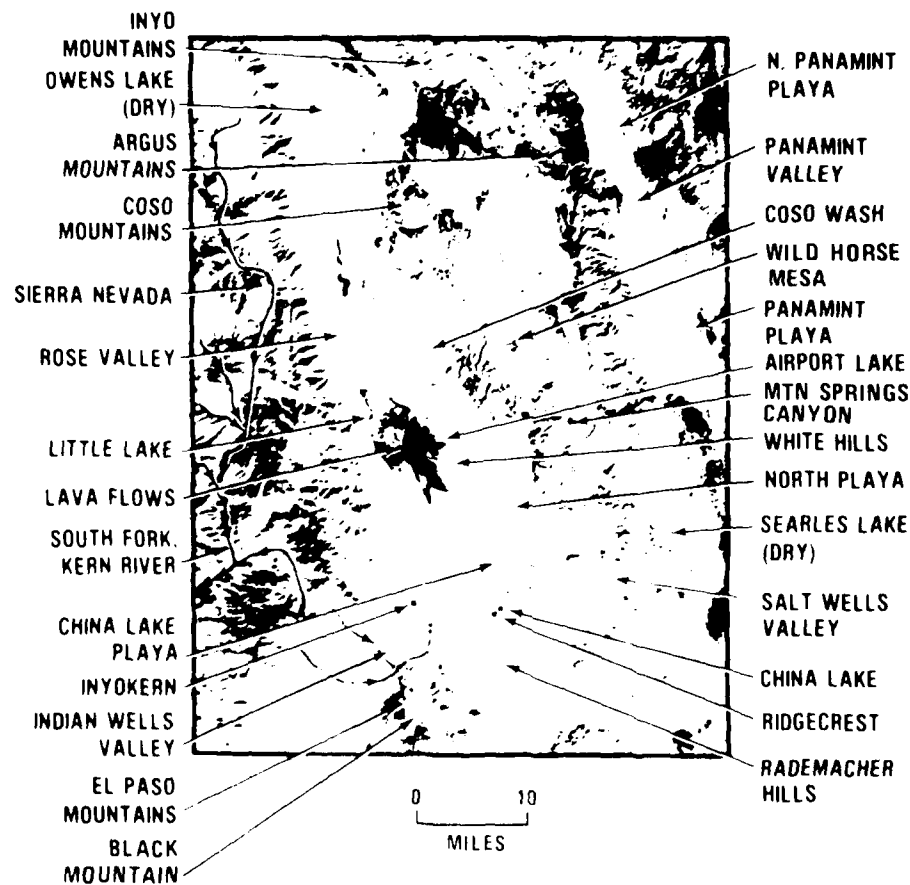
FIGURE 1. Location Map for Indian Wells Valley and Surrounding Area.
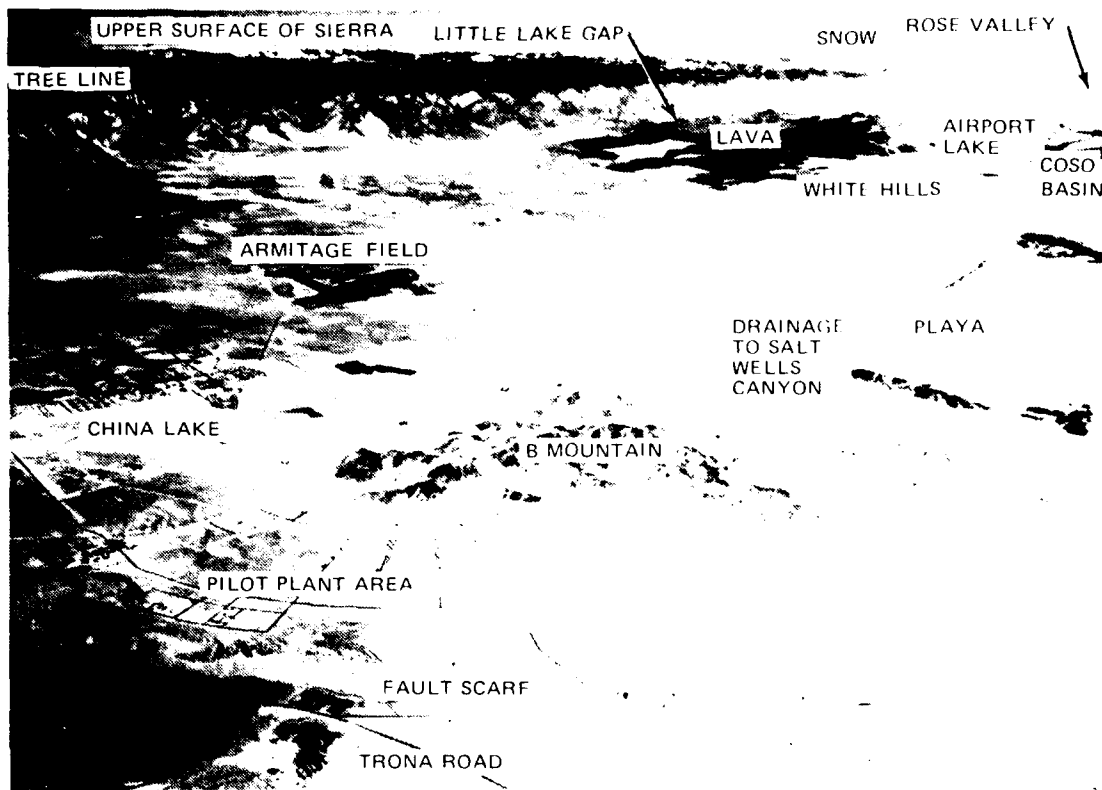
PHOTO 1. Looking Northwest Across Indian Wells Valley. Note the vegetation change from the playa area westward. This photo shows the drainage from Indian Wells Valley to Salt Wells Canyon and Searles Valley.

During the Pleistocene, Indian Wells Valley drained into Salt Wells Valley through the gap where the NWC magazine area is located (see Photo 1). The elevation of the lip of this gap is 2,190 feet. About 40 feet of closure exists in the Valley. If we were to have four times the present rainfall for a few decades, we would have a lake nearly 10 miles across in the east central part of Indian Wells Valley (Photo 2).

PHOTO 2. China Lake Playa After a Heavy Rain. This water is still less than a foot deep.

GEOLOGY OF INDIAN WELLS VALLEY

Indian Wells Valley is a downdropped block of land bounded by faults that separate it from the hills (Figure 2). The bedrock and surrounding hills are hard, impervious granite, granodiorite, and similar igneous rocks about 80 to 100 million years old. Some sedimentary and volcanic rocks rest upon the igneous rock on the north and southwest sides of the Valley. All the rocks are faulted, crushed, and broken in places; the bedrock basin, nearly waterproof, does not conduct much of the water that reaches the Valley. Indian Wells Valley is deepest between Inyokern and the foot of the Sierra. The bedrock floor is repeatedly offset by faults, only a few of which are shown in Figure 2. Granitic bedrock is exposed alongside Highway 14 just west of Inyokern.

Alluvial fans from the Sierra interfinger with younger Valley alluvium between Inyokern and the Sierra. The older alluvium lies upon still older continental and lacustrine beds that probably correlate with the Ricardo and Goler Formations (see the historical geology section that follows). The estimated depth of the formations, shown in Figure 2, is taken as the contact between two seismic velocities, as determined by Zbur (1963), following Dutcher and Moyle (1973, pg. 9).*

The younger alluvium is at the surface all across the Valley to near the main gate of NWC. Older lakebeds from the main gate eastward form the spine of a gently rising hill on which the community of China Lake is built. These lakebeds crop out near Richmond School. Old sediments containing basalt, tuffaceous materials, agate, and other constituents common to the Ricardo Formation crop out near the east end of Mirror Lake. Fanglomerates derived from B Mountain are mixed with these older sediments.**

HISTORICAL GEOLOGY

DEVELOPMENT OF THE DEPRESSION

Indian Wells Valley contains, at depth, 20- to 40-million-year-old continental beds of the Goler Formation. The landscape was then a shallow swale filled with debris from surrounding granitic low hills.***

An active volcanic period around Indian Wells Valley began about 3 to 5 million years ago in the late Miocene. Large amounts of ash and pumice were deposited in the basin, which, for part of this time, contained a large lake. These sediments, buried thousands of feet beneath the Valley floor, are the Ricardo Formation. Portions of this formation are uplifted and exposed by erosion in Red Rock Canyon, Black Mountain, and southeast of the Valley. Volcanism dwindled and the Valley continued to deepen, filling with gravels and sands from the surrounding hills. About 3 1/2 million years ago, the smooth topography began to break up as the land on the north side of the Garlock Fault began to stretch in an east-west direction. Mountains grew and the floors of the Valleys began to sink.

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* I followed Dutcher and Moyle's procedure by dividing the stratigraphic section into only two parts; the procedure is based on Zbur's (1963) carefully done seismic work.
** Most of these features can be seen along the east side of Mirror Lake. For details, the reader is referred to the geologic map by Moyle (1963).
*** Details of the Goler and Ricardo Formations are contained in a paper by Dibblee (1967).
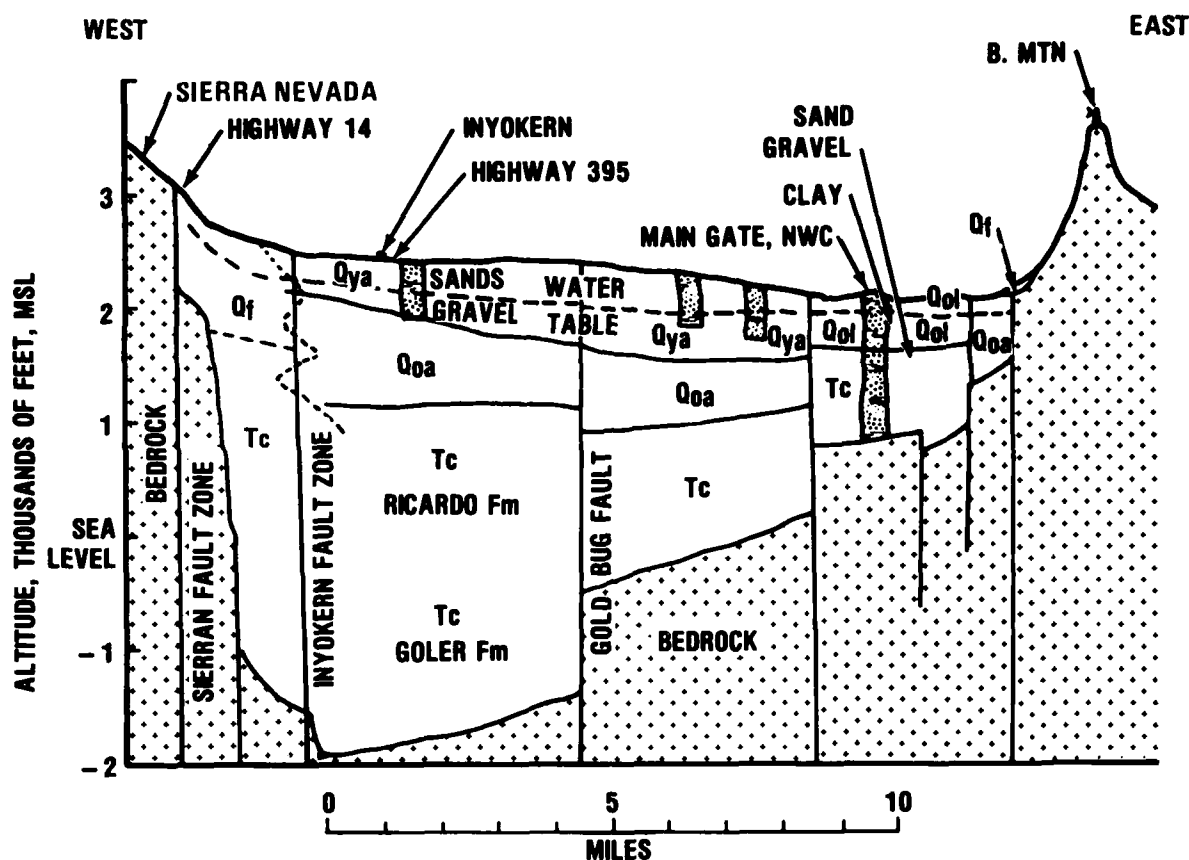
FIGURE 2. Schematic Cross Section of Indian Wells Valley Along Inyokern-Ridgecrest Road.*

Qf   Deposits of alluvial fans from the mountains, including mud flows and gravels. The transmissivity of water varies in these rocks, and consequently, yield water sometimes well and sometimes not.

Tc   Includes deposits of continental origin, such as the Ricardo Formation. These deposits include pyroclastic materials deposited in a desert lake environment, including sandstones, lava flows, and beds of tuffaceous material. The Goler Formation, devoid of pyroclastic materials, is primarily continental sediments derived from a granitic landscape and does not yeld water readily.

Qoa Older allumvium deposited during, or before, the earlier glacial stages (McGee and Sherwin advances). These sediments are well-consolidated and do not yield water readily or in large quantities.

Qya Younger alluvium, deposited in current climatological conditions, is the best source of water in Indian Wells Valley.

Qol Lakebed clays, presumably of pre-Ice Age and Ice Age provenance. These clays yield a small quantity of poor quality water.

Bedrock   Granite and granodiorite are typical of the Sierra Nevada.

* Figure 2 was developed from all available sources of information, with some additions by me. Data from Zbur (1963) and Dutcher and Moyle (1973) are combined with information from Healy and Press (1964). The faults are from my geologic mapping, and correspond with Moyle's and von Huene's mapping in 1960.

DEEPENING OF THE VALLEY

About two million years ago, the Ice Age (or Pleistocene Epoch) began. Rainfall increased; the weather cooled; glaciers covered the growing mountains to the north and the mountain valleys as far south as Big Pine, topping the higher hills to the south of Cottonwood Lakes. The shallow but deepening groove of Owens Valley filled with a coalescing chain of lakes that drained the Mono Lake region through the gap at Little Lake into Indian Wells Valley.

Gale (1913) first described the chain of Pleistocene lakes that existed intermittently during the Ice Age (Figure 3). This chain of lakes began with Lake Crowley, and continued through Lake Owens, Lake Rose, Lake China, Lake Searles, and Lake Panamint to Lake Manly in Death Valley.* All Pleistocene lakes had a high stand of water during glacial advances, and the youngest shorelines are still visible on surrounding hillsides. The shoreline vestiges (see Photo 3) indicate Pleistocene lake levels: Lake Owens stood at 3,990 feet, Lake Rose at 3,550 feet, and Lake Searles at 2,440 feet. Lake China shores have been mapped as high as 2,500 feet (Figure 4).**
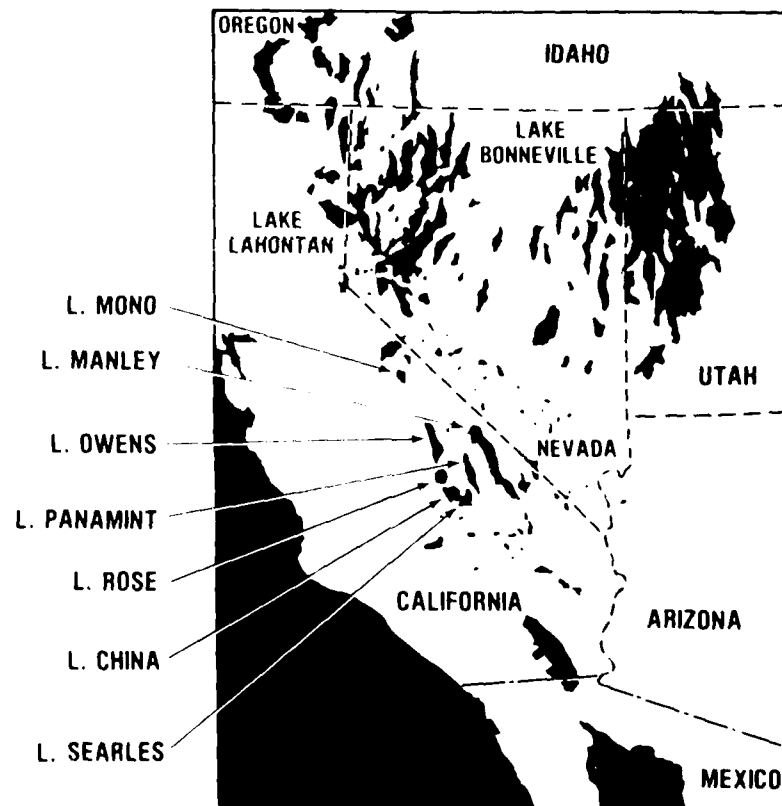
FIGURE 3. Pleistocene Lakes of the Great Basin

* Although Gale (1913) described the Pleistocene chain of lakes, he did not include Lake Rose. I added this lake based on the shorelines on the northeast side of Rose Valley near the pumice mines.

** Moyle recognizes an old stand of the lake at an altitude above 2,400 feet. Recent work by myself in Section 7 to the southwest of Ridgecrest shows an old shoreline with concomitant lakebed sediments at about 2,500 feet. This is a very old stand of the lake that was probably emplaced during the Illinois or pre-Tahoe glacial period.
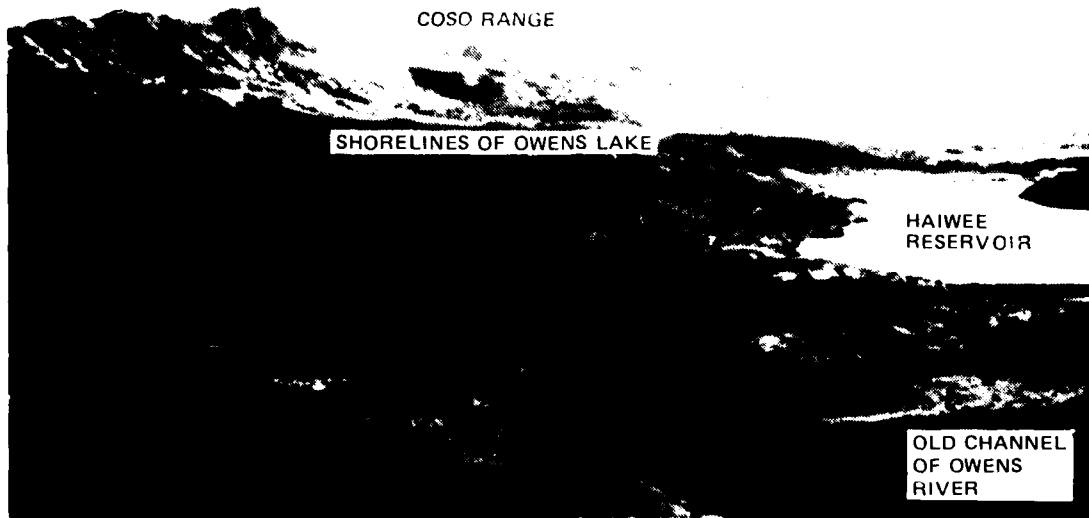
PHOTO 3. Shorelines, Now High and Dry, Show High Stand of Lake Owens About 20,000 to 10,000 Years Ago.
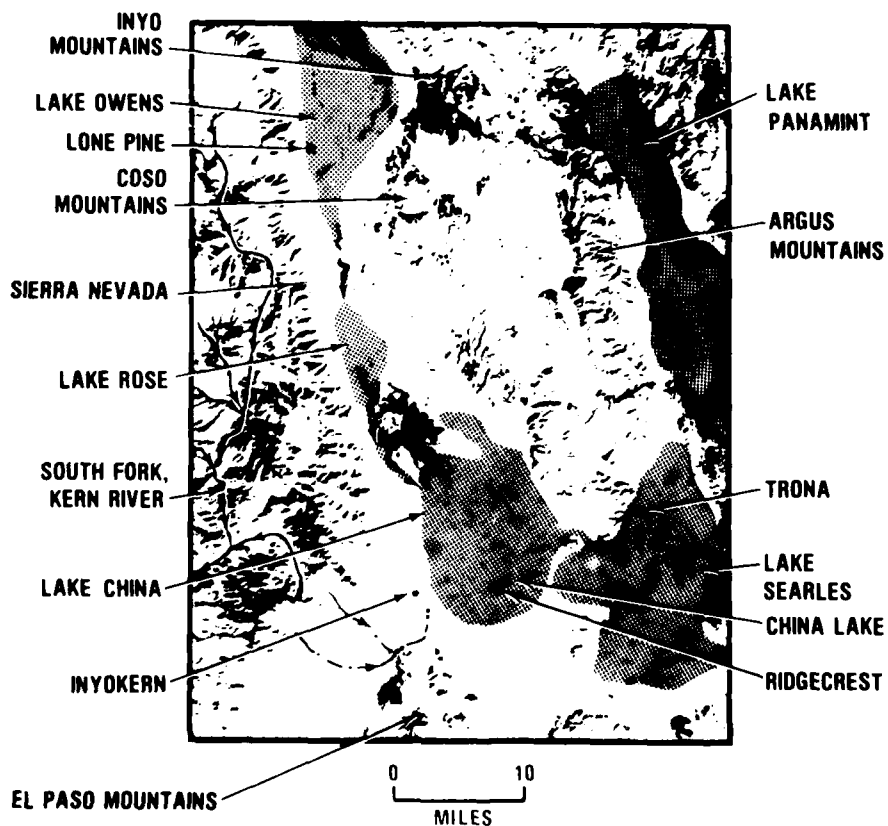
FIGURE 4. Pleistocene Lakes in Indian Wells Valley Area.

The western shore of Lake China reached, at least, to the present site of Inyokern and probably beyond, but sediment deposition covers evidence of older lake shores. The present site of Ridgecrest was covered with water; the eastern side of the lake reached to the top of the Trona grade. The high stand of this lake permitted deposition of clay beds over a large part of the floor of Indian Wells Valley. At times Lake China and Lake Searles inundated their respective valleys and merged into one lake.

The Ice Age is broken into four major glacial advances: the McGee, Sherwin, Tahoe, and Tioga. During the interglacial periods, the ice melted. The climate was hot and dry and the lakes evaporated.

FILLING OF THE VALLEY

The climate of the Indian Wells Valley became cooler and wetter with intense rains during pluvial periods. Debris washed down from the mountains and spread throughout the Valley. Boulders and gravels were deposited near the hills. Smaller pebbles and sand were carried by streams and sheet floods onto the Valley floor. Occasional mud flows reached into the Valley. Fine clay particles remained suspended in the lake water long enough to spread evenly over the flat floor of Pleistocene Lake China. Climatic and geologic changes in Indian Wells Valley since the Tioga advance are reflected in the stratigraphy shown in Photo 4.

Owens River (Photo 3) flowed intermittently into the Indian Wells Valley until about 8,000 years ago (Gale, 1913). The river deposited clays, silts, sands, and fine gravels in China Lake. Larger particles formed a delta at the edge of the lake as the silts and clays spread over the lakebed. Some ground water still trickles across the basalt barrier at Little Lake.

During the Ice Age, an enormous amount of volcanism occurred north of Indian Wells Valley. Centers of volcanic activity developed in the Coso region, south of Big Pine, and to the north of Bishop. The Owens River carried soluble materials from the new volcanic rock

MODERN FILL—AEOLIAN SANDS, SILTS, AND WASHED-IN DEBRIS

ORGANIC LAYER—MARSHY STAGE

INTERMEDIATE FILL—SANDS, SILTS, ETC

CLAY LAYER (TIOGA), DEPOSITED DURING LONG-LASTING DEEP LAKE

PHOTO 4. Construction Pit on China Lake Playa. This photo shows the climatic and geologic changes through stratigraphy since the Tioga phase of the Pleistocene.

through the chain of Pleistocene lakes. Although the Owens River water was fresh, the dissolved solids were salts of sodium, potassium, calcium, boron, and magnesium. During the interglacial periods, the lakes dried and the salts concentrated by evaporation. When the lakes filled during the succeeding glacial periods, the older saline layers were sealed off by newly deposited layers of clay.*

The central portion of Owens Valley was filled with clays** rather than dissolved salts. Indian Wells Valley served as a settling basin for suspended clay, and at the same time collected sodium chloride, sodium carbonate, and some borates. Most of the potassium salts, borates, and sulphates were carried to and deposited in Lake Searles. Water in Lake China was never as deep as in Lake Searles because the Lake China basin filled with sediments from more abundant sources as fast as the Valley floor dropped. Because of the fill and evaporate cycles during the Pleistocene, the main clay playa and beds of clay beneath China Lake are saturated with water containing sodium chloride, sodium carbonate, and some borax. In parts of the Valley, layers of clay (Photo 4) partially seal older sediments containing saline layers from the fresh water above.

The Indian Wells Valley filled to its present depth with as much as 6,200 feet of sediments (Figure 2). Some lava flows are interbedded with the sediments. The central and east central parts of the Valley are filled with an irregular clay plug at least 500 feet deep. Discontinuous beds of clay separate the sediments at depth and restrict the natural movement of water. Such deposits are said to be "confining" beds, although they usually only impede the underground flow.

FAULTING – THE EFFECT ON HYDROLOGY

The floor of Indian Wells Valley is intensely faulted (Figure 5).*** Some of the faults show considerable horizontal and vertical displacements that affect in several ways the flow of ground water. In sound rock, fault zones often contain impervious layers of clay that serve as ground-water barriers. Water creeping downhill from the mountains collects behind the fault zone until the water level reaches the surface and overflows. The Valley takes its name from some galleries dug horizontally through a fault zone near Indian Wells Valley Lodge on Highway 14.

Large fault zones may store large amounts of water in considerable quantity by forming voids in otherwise solid rock. Such faults are sought by people wishing to develop water sources in granitic terrain, and in many places these faults are the only source of water. Faults often serve as ground-water barriers beneath alluvial fill because faults create clay diaphragms that act as dams. Faults nearer the surface may not influence ground water much if the soil is too weak and unconsolidated to be converted into clay, or if not enough movement has taken place in the newer fill.

A fault may serve as a water barrier, serve as a horizontal or vertical channel for transport along its length, or have different hydrological effects at varied depths and locations Photo 5 shows a fault that serves as a ground-water barrier and another fault that served as a horizontal channel for the Owens River.

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* See any of Smith's papers cited in the bibliography for details of the filling and emptying of Searles Lake.
** See Smith and Pratt (1957) for a description of the logging of a well in Owens Lake.
*** The faults are taken from the work of von Huene (1960), Zbur (1963), and Moyle (1963), and from my air photo interpretation
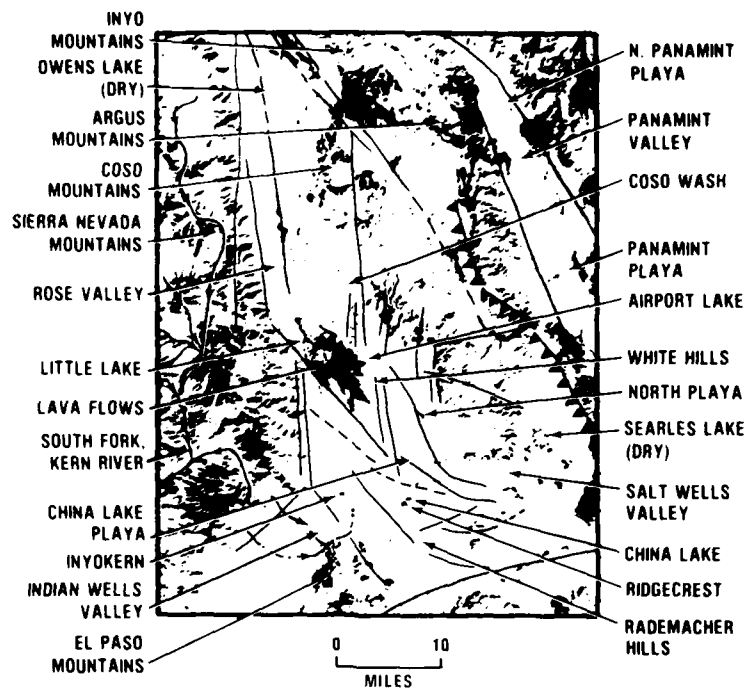
FIGURE 5. Faults in the Indian Wells Valley Area.
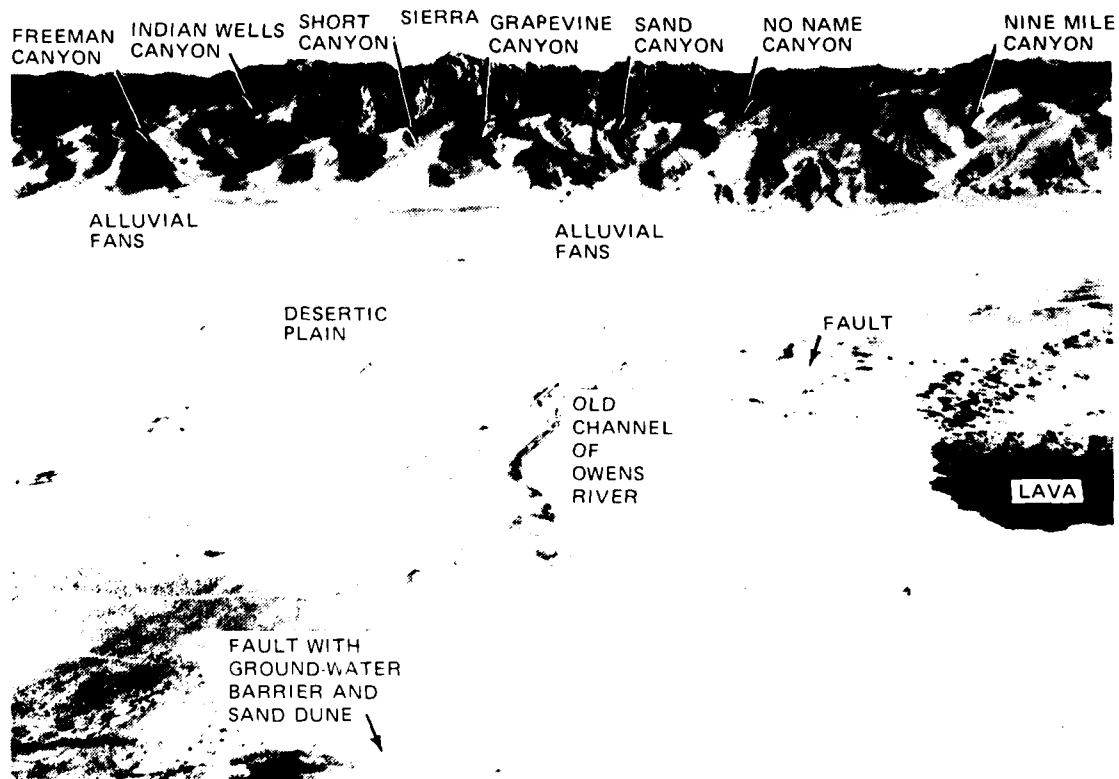
PHOTO 5. Looking Westward Across Indian Wells Valley to the Sierra Nevada.

RAINFALL

AMOUNT AND DISTRIBUTION

The Indian Wells Valley region is arid; rain and snow vary in frequency, amount, and locality. The average rainfall is 5 to 6 inches per year; rainfall increases to about 10 inches in the Argus Mountains and to 10 inches or more per year along the crest of the Sierra (Table 1, adapted from Rantz, 1967). Further west, rainfall is much greater, but our Valley does not benefit from that.

In an average year, between 400,000 and 500,000 acre-feet of water fall as rain or snow upon the 1,100 square miles of the catchment basin that furnishes water to the ground-water supply of Indian Wells Valley. Little of the rain that falls on the Valley itself reaches the ground-water table. Water does not seep in rapidly over much of the Valley and most is evaporated by winds or transpired by plants; 90 to 100 inches of water a year can evaporate (Photo 6). The water that does seep in becomes a part of a shallow, perched aquifer under China Lake playa.

The Valley catchment areas and the rainfall distribution are shown in Figure 6 (taken from Rantz, 1967). The hatched areas show where enough bare rock is exposed to make catchment of water reasonably easy. The rainfall is generalized because no actual measurements of rainfall exist for most of the area, except for a few rain gauges in the Valley. Absolute values are not known and variability from year to year is high, but the rainfall, estimated by various means, can serve as a guide to estimate the available water.

TABLE 1. China Lake Watershed.

Place	Area, sq mi.	Average elevation, ft	Average rain, in./yr	Rainfall, acre-ft./yr	Rain total, percent
Sierra Nevada	183	6,500	10	100,000	0 53
Coso	165	5,000	6	53,000	0 26
Renegade	12	5,500	6	4,000	0 02
Mountain Springs	20	5,500	6	6,000	0 03
Argus	78	5,000	6	25,000	0 08
Rademachers	24	3,000	5	6,000	0 03
El Pasos	33	3,500	5	9 000	0 04
				203,000	1 00

PHOTO 6. Sailing on Mirror Lake. This is one of several usually dry playas of Indian Wells Valley. The freestanding water, a result of runoff, is lost to evaporation.
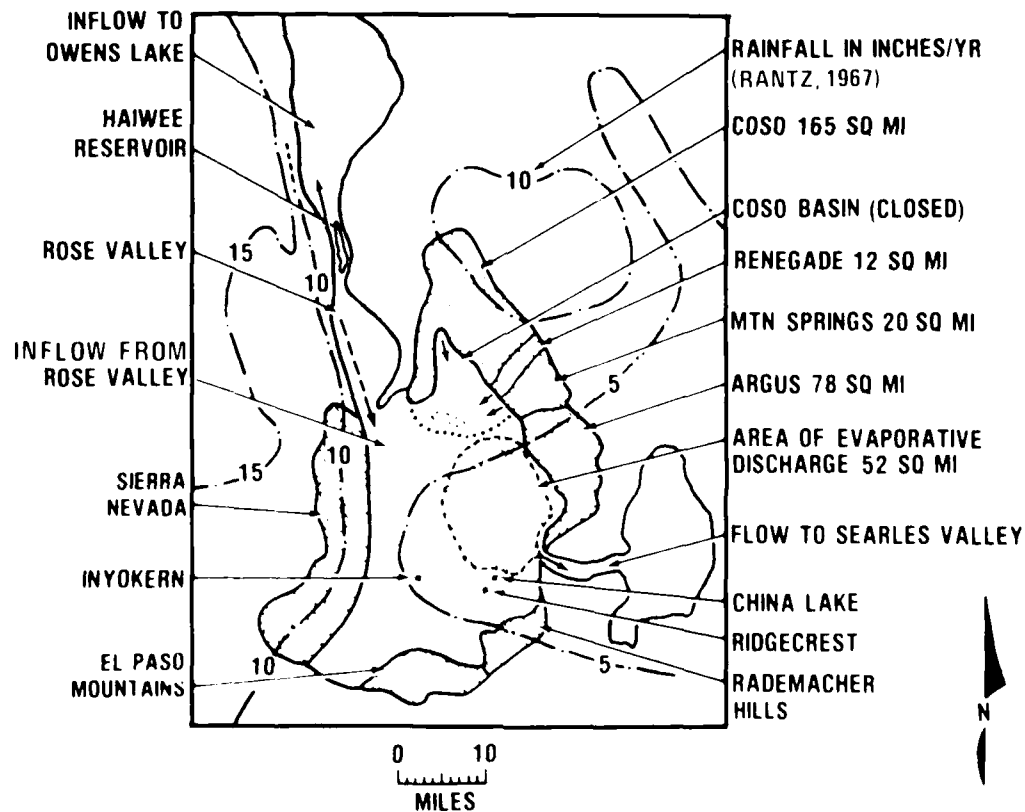
FIGURE 6. Catchment Areas for Indian Wells Valley Ground Water.

GROUND-WATER BUDGET

In the Indian Wells Valley, some rainwater or melting snow runs off on the rocky surface until patches of alluvium are reached. The water then collects in streams and soon soaks into the superficially dry stream beds and continues downhill in the sands and gravels, out of sight. Eventually this water reaches the Valley fill and enters the ground-water supply. *Only a narrow zone, bordering on and containing bare rock, really adds much water to the ground-water storage (Photo 7).**

(a)

OWENS PEAK

METAMORPHIC ROCK

GRANODIORITE ROCK

ALLUVIATED SLOPES
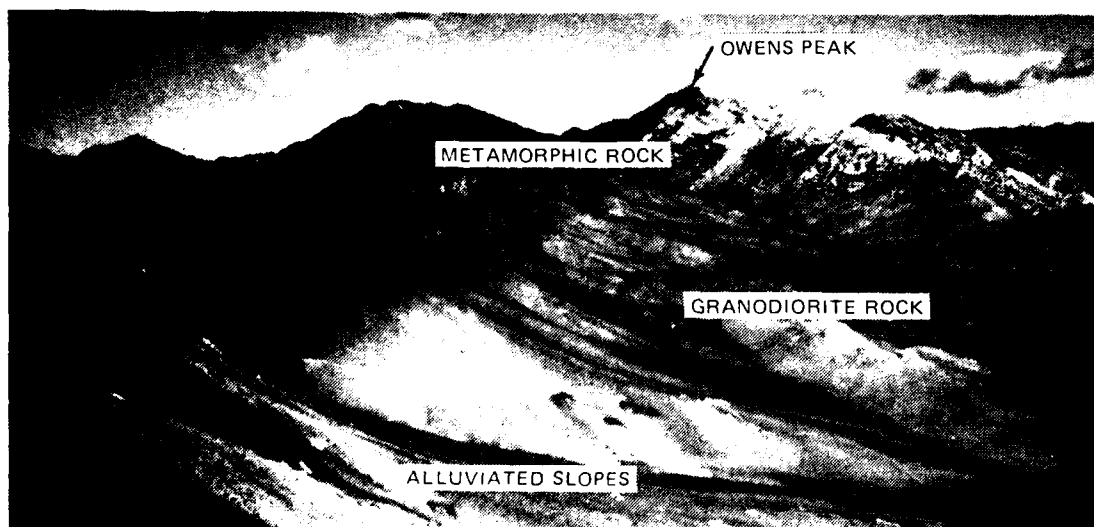
(b)

PHOTO 7. Sierra Nevada Catchment Area for Indian Wells Valley. (a) Rocky surface on Sierran Crest permits water to run off into the soil. (b) View of the Sierran front west of Inyokern. Granodiorite and metamorphic rocks permit water to collect and run into the alluviated slopes from whence it trickles underground through the canyons and into the Indian Wells Valley ground-water supply.

* In areas covered by lava, some of the water enters the ground-water system by running into cracks in the lava flows.

The amount of water that eventually enters the water table is miniscule compared to total precipitation. As a rule of thumb, little rainwater reaches the ground-water table unless 16 or more inches of rain fall per year. Even then, less than 5% ends up as ground water (Blaney, 1959). The remaining water wets the rocks, fills the cracks and crevices, and coats the sides of rocks and sand grains with pellicular water. This water is soon evaporated by the wind, or is used by xerophytic plants and transpired to the atmosphere. *Of the half-million acre-feet of rain falling onto the catchment basin each year, only about 11,000 acre-feet enters the ground-water supply of Indian Wells Valley.**

Areas of exposed bedrock in the various watersheds contribute to the ground water in Indian Wells Valley, as shown in Table 1.** The relation of rainfall to runoff is complex and depends on the type and duration of the storm. Most storms normally produce little or no runoff. The relationship to ground-water recharge is even more complex. The runoff from the Coso Basin, Renegade Canyon, and Mountain Springs Canyon does not reach China Lake, but instead flows into Airport Lake. The ground-water recharge from these areas may not reach Indian Wells Valley proper. We receive only 20 to 50 acre-feet of water per year by filtration through the gap at Little Lake (Bloyd and Robson, 1971).*** The Little Lake gap is shown in Photo 8.
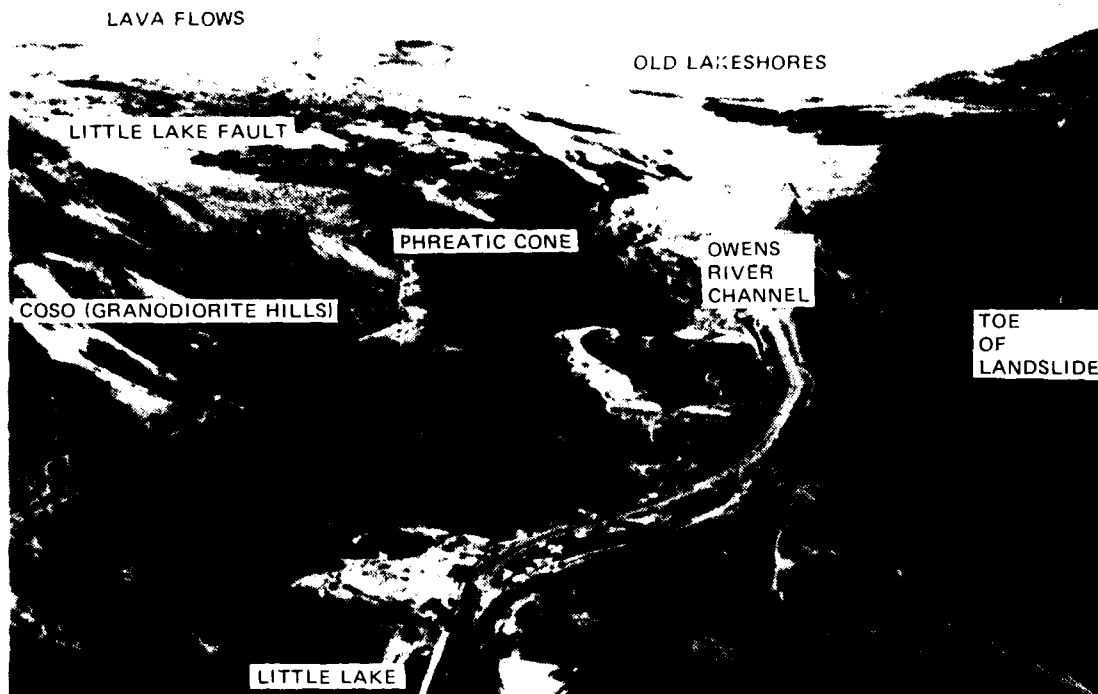
PHOTO 8. Gap At Little Lake. The Owens River drained through the gap into Indian Wells Valley.

* Justification for this amount of water entering the ground-water supply is developed in the succeeding pages.

** The information in Table 1 was derived from rainfall values given by Rantz (1967) using areas measured by a planimeter from the 1:62500 quadrangle maps of the areas involved. This same information is given in Figure 10, greatly reduced.

*** So little water enters Indian Wells Valley from the Little Lake gap that it does not matter much in the overall water budget of the Valley. The amount of water entering the Indian Wells Valley through the Little Lake gap is estimated differently by different individuals. Bloyd and Robson's (1971) figure is probably the most accurate because ground-water contours fit the models. "Hydrology Task Investigation" in Rockwell's preliminary Coso Environmental Statement Study (pp. 82 and 100-112) sets the inflow limits between 45 and 500 acre feet per year. These limits give a generous upper limit based upon calculations of the cross section of the channel and an estimate of the hydraulic gradient.

In poor water years, disproportionately less water enters storage; in good water years, disproportionately more enters. If the rainfall were to double, the amount of water entering the storage would more than double, unless the increase were sustained long enough to permit vegetation to develop to the point where evapotranspiration more than doubled.

GROUND-WATER DISCHARGE AND RECHARGE: THE WATER TABLE

No easy method exists for assessing the total annual ground-water recharge to the Valley. Two techniques yield reasonable results: (1) estimating the discharge by estimating the evaporation, and (2) estimating the inflow from the shape of the water table (the ground-water level).

Ground water fills the accessible pores between the grains of sand, rock, and gravel. Water does not run out of the bottom of the Valley because the bedrock is nearly impermeable and any voids are filled. The water wets the particles of earth and keeps the sediments damp a few feet above the actual water surface.

If water is not confined by an impervious layer, the water table is a subdued replica of the surface topography. The water table is higher where it enters the Valley – near the hills and canyon mouths – than it is in the central portion of the Valley where water is pumped or is lost by evaporation from around the playa or by outflow (Figure 6).*

In closed basins, ground water collects until it fills all the spaces in the sediments and finally reaches the surface in the lowest part of the Valley. When the water approaches the surface, it becomes available to plants. If water flows to the surface faster than plants use it, a freestanding water surface develops on the lowest portion of the playa, from which it evaporates.

Bad Water, in Death Valley, is a freestanding water surface. The water is so saline that plants cannot grow and water is lost only by evaporation. A similar freestanding surface can be seen at NWC just north of the old Lark site (Photo 9).** This water is fairly good and a tule patch is growing; desert chub thrive in the pond. In another site on-Center, some 50 acre-feet of water per year seep into Salt Wells Canyon.***

In Indian Wells Valley, the water table almost surfaces at the edge of the central clay plug, as evidenced by measurements and plants growing around the edges of this plug. Under typical conditions, not enough water is available to keep the surface wet, although the water table is about 3 feet or less in the central part of the playa. If there is no consumptive water use, the amount of water used by vegetation and evaporated from the surface equals the amount of water entering the basin.

* If impervious layers in the central part of the Valley impede the flow of water to the surface, the phreatic level in the central part of the Valley may be above the surface of land; but water does not reach the surface unless some vertical channel is available. Sometimes artesian wells can be developed in the playa area because of this factor; there is an artesian well at Paxton Ranch that penetrates these impervious sediment layers (Photo 11).

** The freestanding water near the old Lark Ramp was originally a damp spot with some tules. It is now an open-water surface, fed by leakage from the sewer ponds.

*** The estimates of outflow through the magazine area to Salt Wells Valley was originally made by Kunkle and Chase and repeated by Dutcher and Moyle (p. 27). It is doubtful if this much water actually escapes. As with the inflow from Rose Valley, the amount is unimportant in the total water budget. The inflow does make a difference, however, in the chemistry of the water in the upper aquifer on the China Lake playa because it helps transport salt out of the Valley, albeit not very much.

PHOTO 9. Looking Northwest Over "B" Mountain Across Indian Wells Valley

ESTIMATING EVAPOTRANSPIRATION

Without consumptive water use or export of water, eventually the amount of water escaping by evapotranspiration must equal the amount of water entering the ground-water system. By measuring or estimating the average evapotranspiration, the input can be estimated. Figure 7 shows the distribution of the Valley's plant and soil types. The amount of water transpired by the plants or evaporated from the different types of soil can be estimated. Table 2 shows that the amount of water discharged from each area can be calculated and the total water discharged determined by adding the contributions from each individual area.* For an example, see Blaney, 1951.

FIGURE 7. Distribution of Plant and Soil Types in Indian Wells Valley. Table 2 describes the distribution units in this figure.

* The reader is referred to the following publications because a synopsis of the whole system would be a paper in itself. The system was developed originally by Lee (1913) and subsequently improved and elaborated on by Blaney and Criddle (1949) and Blaney (1951). The details of this method are given in Dutcher and Moyle 1973, pp. 22-23, and in Kunkle and Chase (1969).

TABLE 2. Discharge of Ground Water by Evapotranspiration *

Distri- bution unit	Description	Area acres	Depth to water, ft		Evapotrans. ft/yr		Discharge, acre-ft/yr		Changes acre ft/yr
			1912	1953	1912	1953	1912	1953	
I	Bare clay, wet, alkali film, some standing water, includes 6 acres (ark pond)	1,206	3.5	2.5	0.8	1.3	995	1,685	+690
II	Playa surface, bare hard clay, moist, little alkali	5,360	3.5	5.0	0.5	0.1	2,730	580	-2,150
III	Phreatophyte fringe, salt grass, pickleweed, puffed soil moist	3,400	4.5	4.5	0.7	0.7	2,130	2,130	+0
V	Border area sand, creosote, bare alkali crust, puffed, puffie moist, alkali pan	470	4.5	4.5	0.5	0.5	240	240	+0
V	Transition zone from playa to desert sand, pickleweed, salt grass, alkali crust, moist to dry	3,800	5.5	6.2	0.4	0.3	1,520	1,160	360
v	Drainage courses, core areas, sparse plants, crusty alkali	4,390	5.5	6.0	0.4	0.3	1,980	1,460	520
	Dunes and blowout areas, sebkans sparse plants, sebkans moist	14,390	4.5	5.0	0.5	0.3	1,730	1,030	700
TOTAL Discharge of ground water by evapotranspiration							11,325	8,285	3,040

The usual desert shrubs, called xerophytes, exist on pellicular water, occasional rainwater, or sheet floods (Figure 8). These plants do not normally live off ground water because they can neither tolerate alkali nor compete well with other plants.

In areas where the ground water is near the surface, a different assemblage of plants, the phreatophytes, use the shallow ground water, as shown in Figure 8. In Indian Wells Valley, the most important phreatophytes are pickleweed and saltgrass. These plants draw water from depths of less than 10 feet and when the water table drops to about 15 feet, they die or do not reproduce. Salt cedar and cottonwood, as well as alfalfa, draw water from far below shallow ground water levels.

Figure 9 and Table 2 show the amount of water evaporated from the ground and transpired by these plants per year as a function of water depth. Natural evaporation of ground water takes place in a 33,000 acre area in the Valley. Climatic conditions such as strong winds and high temperatures markedly increase evapotranspiration, which can be as high as 10 feet per year from a freestanding water surface.

C. H. Lee (1913) used the process described above to estimate the evapotranspiration from Indian Wells Valley. He concluded that the annual discharge was about 31,600 acre feet per year. His data, later used by others, show that the discharge was about the same in 1920.
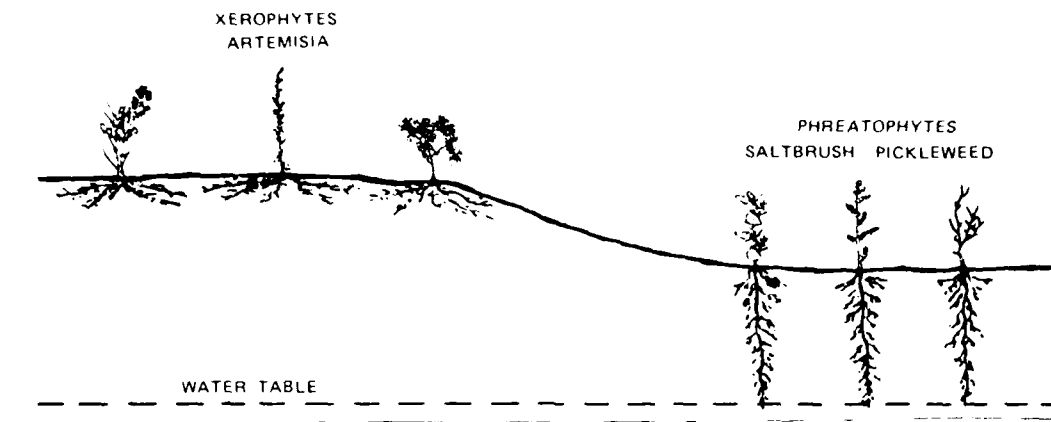
* Table values adapted from Kunkel and Chase, 1969.
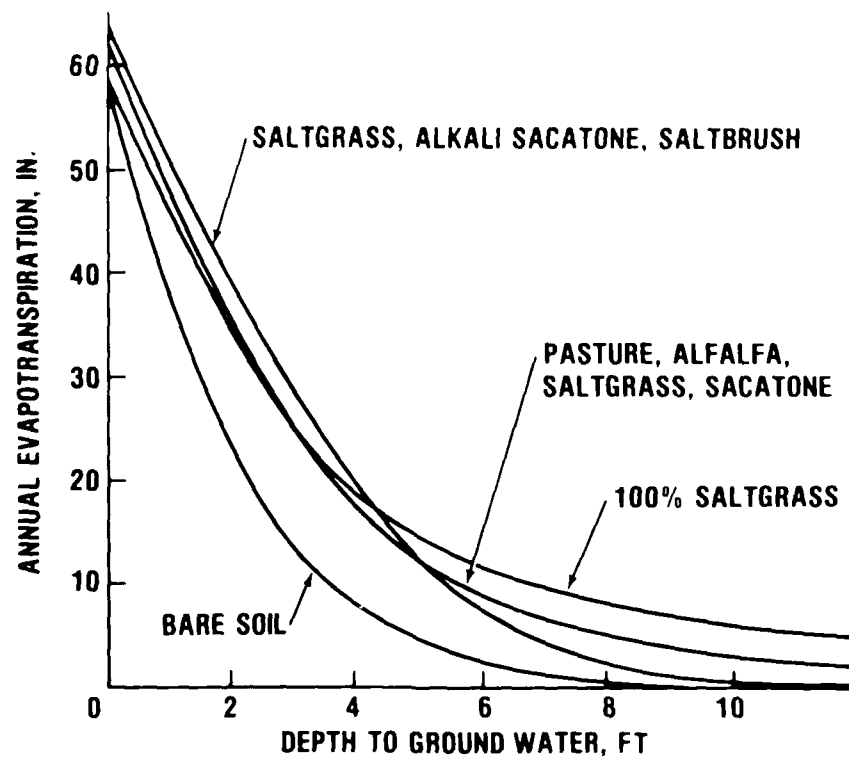
FIGURE 8. Xerophyte and Phreatophyte Root System.

FIGURE 9. Evapotranspiration in Owens and Indian Wells Valleys

Kunkle and Chase repeated Lee's calculations using more careful speciation of phreatophytes and more precisely measured areas. Kunkle and Chase estimated an annual discharge of 11,000 acre-feet per year for 1913 and 1920 and an 8,000 acre-feet discharge for 1953. They attributed the difference between Lee's results and theirs to better data, use of aerial photographs and maps, etc. The difference between the values for 1920 and 1953 is attributed to the lowering of the superficial water table.

Kunkle and Chase's estimates are based on assumptions concerning surface conditions; if corrections are made to these assumptions, the evapotranspiration estimate is reduced. Thus for 1953, the estimate is reduced by 3,300 acre-feet per year. The reduction of 4,700 acre-feet per year is a reasonable correction to evapotranspiration. On the other hand, Kunkle and Chase's computations were made using an average depth to water in the selected areas. They should have averaged the evapotranspiration rather than the depth to water, because evapotranspiration is a strong, nonlinear function of depth.

Averaging evapotranspiration makes a considerable difference in estimates. For example, consider an area that has a uniformly slanting water table so that at one end the water depth is zero and at the other end the water depth is 10 feet. The average depth is 5 feet. The evapotranspiration at the shallow end will be about 6.8 feet per year, while at the deep end the evapotranspiration will be only a little more than zero; thus the evapotranspiration derived from this averaging process will be about 0.3 feet per year for bare soil. In reality, the estimate should be about 1.4. This error in computation is significant, and although the example is extreme, it is not beyond the range of what might happen in practice. Depth to water on a playa must be measured with some care because shallow wells often have phreatic heads below the land surface. On the other hand, deeper wells often have phreatic heads above the land surface because of the nature of the recharge and the confinement by the upper playa clays.

When calculations such as evapotranspiration are made, rainfall on the floor of a desert basin is not generally considered as a factor. However, if one considers the unusual rainfall in Indian Wells Valley between 1975 and 1982, including this factor into the calculations would make a difference. The average rainfall in the Valley has been 7.01 inches; we appear to be in a wetter than normal period. This rainfall results in the increase of some 19,000 additional acre-feet of water on the area considered by Kunkle and Chase, but does not include runoff onto the playa area. This 19,000 acre-feet may be an important amount of water because some 8,000 acre-feet more than previously calculated fell upon the surface and presumably evaporated.

Although some water evaporates, the rest sinks into more porous ground in about 25% of the area involved in these calculations. If xerophytes do not grow in this area, water is not transpired and the evaporation is less. Moreover, most rain falls during the winter months when the evaporation rate is low. For example, if 4 inches of rain falls during January, only 2 inches of rain evaporates. The remaining 2 inches may raise the water level in the sediments by a foot. The playa area is underlain by impervious clay, and any small rainfall, which ordinarily could be expected to only wet the ground, accumulates on top of the clays and upon water migrating from depth to surface.

The effects of rain and runoff must be evaluated before an accurate estimate of transpiration and evaporation is made. If these factors are not included in the calculations, the estimates must be regarded with less confidence than if the water balance could be worked out. For example, if the 19,000 acre-feet of rain that falls on the playa is subtracted from Lee's figure of 31,600 acre-feet of evapotranspirative discharge, 12,600 acre-feet per year of discharge remains. This remainder would be gratifyingly close to what it should be were the problem not complicated by other factors such as molality of the ground water

and the resulting vapor pressure lowering by the solutes. More effort must be directed toward estimating the discharge by evapotranspiration if credible figures are to be obtained.

CALCULATING UNDERFLOW

The flow of underground water can be calculated by using Darcy's Law: Water's speed through a porous media, such as soil or alluvium, depends upon the materials' permeability and the slope of the water table. Because the direction of flow is always down-slope on the water table, across the contour lines of water level, the usual method is to calculate the flow across the full length of a contour line. This calculation may be done by hand or by computer model. The computer model can, of course, determine a great many other factors as well as the flow, and we will discuss this subject later. We will first consider some more simple calculations.

The flow of underground water may be calculated by using the slope of the water table, the length of the contour line, and a factor termed transmissivity, T. If one knows each of these values for each point along the line, it is possible to add up the flows and find out how much water is flowing downhill into the Valley. The slope of the water table, called the hydraulic gradient, is determined from the level of water in wells.

The transmissivity of water is the rate in gallons per day that flows through a 1-foot-wide section of sediments when the hydraulic gradient is 1 foot per foot; it is the average value of the permeability taken over the whole of the saturated section, multiplied by the thickness of the saturated section capable of conducting ground water.

Transmissivity is usually determined from well tests. The well is pumped at a known rate, and the drawdown of the water measured. The pumping rate in gallons per minute divided by the drawdown is called the specific yield of the well. The specific yield of the well is proportional to the transmissivity coefficient. The constant of proportionality depends upon factors such as the geometry of the well, the rate of pumpage, and the types of sediments near the well.

South and West Sides of the Valley

Kunkle and Chase calculated the underflow across the 2,200 foot water table contour as it existed in 1920 and 1921. The water table's natural recharge was balanced by natural discharge, although 1,000 to 2,000 acre-feet per year were pumped. This amount of pumping would not affect Kunkle and Chase's results, but might make the underflow seem a little higher, depending on the location of the pumping.

Kunkle and Chase were able to make calculations only for the south and west sides of the Valley because no information was available for the north and east sides of the Valley Kunkle and Chase estimated the length of the contour line, took an average value of the hydraulic gradient, estimated the transmissivity from some test wells, applied a correction to the transmissivity for the depth of the well, and arrived at an average value of 200,000 gallons per day per foot, per unit hydraulic gradient (Figure 10). Kunkle and Chase obtained a value of 15,000 acre-feet per year as the recharge by underflow from the west and south sides of the Valley. This procedure for adjusting the transmissivity for the depth of the well is not customary and leads to an estimate of transmissivity that is high by a factor of about 2. A value of 7,200 acre-feet per year is obtained using figures and transmissivity actually observed from pumping tests. No correction for the decrease of permeability with depth was made.

**GROUND WATER
CONTOURS**

$$Q = \sum_{A}^{B} \left[\frac{h_3 - h_1}{D} \right] \Delta I \ T_n$$
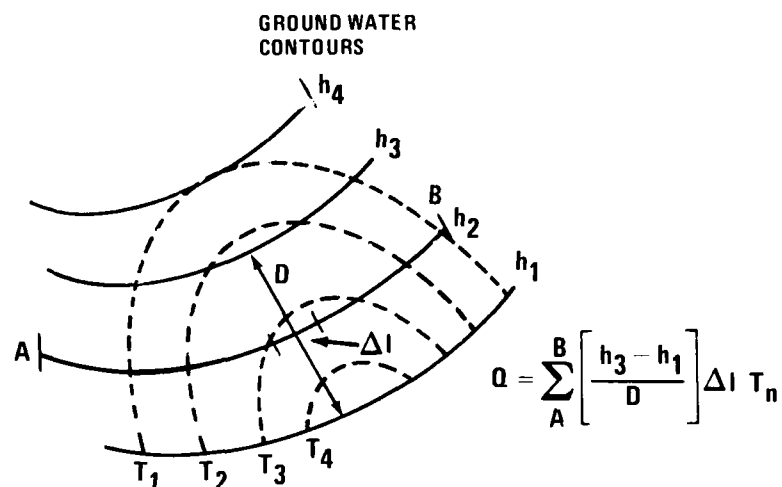
Contours of h_n represent altitudes of the ground-water table; T_n is the average value of transmissivity between the dashed countours; ΔI is the increment in length along the water-level contours; and D is the distance between the water-level contours This sum, from A to B, gives the flow Q, across contour h_2

FIGURE 10. Ground-Water Flow Formula.

Dutcher and Moyle calculated the transmissivity for various parts of the Valley and prepared a map of this parameter but did not recalculate the recharge. Because the average value of transmissivity was different from *Kunkle and Chase's, I recalculated the underflow* using Kunkle and Chase's water-level map for 1920 and 1921 and the transmissivities by Dutcher and Moyle. This led to an underflow calculation of 13,100 acre-feet per year. I then used the 1920-1921 map prepared by Dutcher and Moyle, made the same calculation, and obtained 13,200 acre-feet per year. The two water-level maps are somewhat different because Kunkle and Chase did not know about some faults and ground-water barriers.

The values of transmissivity plotted by Dutcher and Moyle are probably too high; they used a constant of proportionality of 2,000 between specific capacity and transmissivity instead of the more usual factor of 1,200 to 1,500. The range of reasonable values may be shown as the following: if a factor of 1,200 is used, the underflow from the west and south is 7,200 acre-feet per year; if an intermediate value of 1,500 is used, the underflow is 9,900 acre-feet per year.

Bloyd and Robson (1971) prepared a computer program to explain the functioning of the ground-water system in Indian Wells Valley. A map of transmissivity is a product of their calculation Bloyd and Robson arrived at an average recharge of only 9,850 acre-feet per year for the whole Valley. I obtained 9,700 and 11,000 acre-feet per year, respectively, for the inflow from the west and south sides of the Valley by using Bloyd and Robson's 1971 values of transmissivity and the original maps for 1920-1921 by Kunkle and Chase and Dutcher and Moyle. Some fraction of the flow was caused by pumping within the space downstream of the 2,200 foot contour. The various estimates are shown in Table 3. *In summary, the underflow into the recharge across the 2,200-foot contour in 1920-1921 from the west and south sides of the Valley was between 7,200 and 13,000 acre-feet per year.*

TABLE 3. Summary of Underflow From West and South.

Transmissivity source	Map		Comments
	Kunkle & Chase	Dutcher & Moyle	
Kunkle & Chase, 1955	15,000		Trans too high because of corr for depth of well
Kunkle & Chase, corrected	7,200		Trans as observed
Dutcher & Moyle, 1973	13,100	13,200	Trans from well tests but multiplied value for IWV
Dutcher & Moyle, lower limit	7,200	7,900	Trans multiplied by more usual factor, possibly low
Bloyd & Robson, 1971	9,700	11,000	Trans derived from computer model
Bloyd & Robson, 1971	6,700		Calculated by computer model

North and East Sides

The contribution from the Coso and Argus Ranges to the ground-water recharge of Indian Wells Valley is unknown. Rain and snow in the two mountain ranges should contribute considerable recharge; the catchment area is greater there than in the adjacent Sierra Nevada, although the rainfall is less. Table 1 (Page 17) shows that about 40% of the rain falling on the catchment areas of the Valley falls in the Coso and Argus Ranges. Just how much of this water flows into the ground-water system has not been determined.

When Bloyd and Robson were preparing their computer model of the ground-water system, they tried to estimate the rainfall in the Coso and Argus Ranges on the basis of area and altitude. They found this led to too much recharge from the Coso and Argus Ranges and not enough from the Sierra Nevada. Bloyd and Robson then used a trial and error process to estimate how much water came from that area by matching up different values of recharge with the configuration of the water table as it existed in 1920-1921. They concluded that 68% of the recharge came from the Sierra and 32% from the Coso and Argus Ranges.

Water Wells. No wells existed north of the north playa of China Lake in 1920-1921, so the configuration of the water table in that region is unknown—a condition that still exists. Hence, it is not possible to perform an underflow calculation like that used in the western half of the Valley. Dutcher and Moyle show values of transmissivity and storage for the area, based on sediment types. These values have not been checked by pumping tests, except on the extreme north of the China Lake sediments, just to the south of the White Hills.

Some information about the area north of the White Hills (Photo 10) is available, thanks to the diligence of Moyle, who published a collection of information on water wells in this area.* He examined every well in the Valley, looked at seismic shot holes, and logged the water level in holes dug for other purposes.

* Moyle gives all the data available in 1963. This document, invaluable in reconstructing the ground water situation, contains a well-detailed geologic map that can scarcely be improved by today's state of the art mapping techniques.
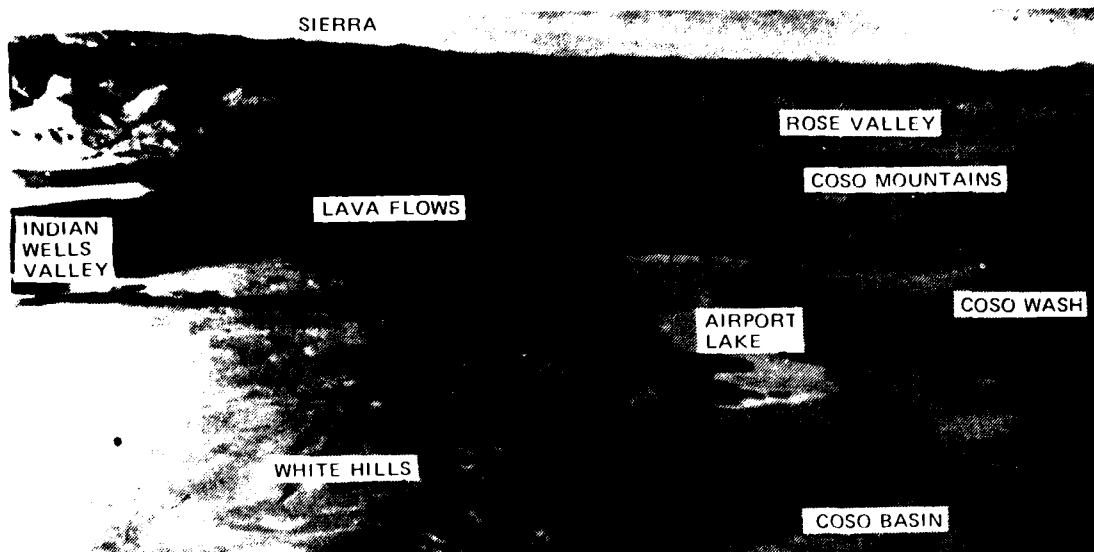
PHOTO 10. View of the Sierra Nevada, Coso Range, Coso Wash, Coso Basin, and White Hills From Southeast. The amount of ground water recharge from north of the China Lake playa is unknown. China Lake playa is to the south.

One well, 24/39-11 K 1, drilled on the axis of the White Hills in 1956, reached a depth of 500 feet without encountering water. The bottom of the hole is at 2,170 feet above mean sea level (MSL), some 17 feet deeper than the water level in the nearest wells to the south of the White Hills. The White Hills consist of older, tighter sediments, but the permeability is high enough that some water should pass through the White Hills. This hole should have had water in it at 2,190 feet MSL, or higher.

Roland von Huene drilled a number of holes in and around the playa of Airport Lake (Photo 10) in 1954-1955 and did an excellent study of the sediments in Airport Lake based on these holes. One hole, 23/29-22 N 1, a short distance north of the playa, was dug to a depth of 107 feet. This water, which should have been fresh, was brackish. The water table was at 2,197 MSL.

The other well in Coso Basin (Photo 10), 24/40-6 A 1, located about a mile to the southeast of the eastern end of Airport Lake, had water at 2,196 feet MSL in 1946. The water was salty and useful only to water cattle.

This particular part of the Valley is traversed by myriad north-south faults that form a complicated series of ground water barriers. Moreover, the structure is further complicated by the northwesterly trending Wilson Canyon fault; the upraised, folded, and perhaps overthrust older, less permeable sediments of the White Hills; intrusions of volcanic rock into and through the sediments, and a line of volcanoes to the west of Airport Lake.

The quantity of water flowing into Indian Wells Valley from Coso Wash (Photo 10) is important to the development of our water supply, but not as much water is reaching the Valley water table as the computer model predicts. Until some test wells are sunk in the Coso Wash region, we will not know how much water is located there. Figure 11 shows the extrapolation of the water table distribution in 1920-1921, as compared to the two wells for which we have some information.

Water Basins. In 1978 Duffield and Smith said an underground stream channel leading from Rose Valley (Photo 10) via the southern end of the Coso Range into Indian Wells Valley "may provide a major conduit for ground water to help charge the heavily pumped subsurface waters of the China Lake Basin." Nothing in the hydrology supports this assumption. Moreover, geologic mapping proves that the buried channel does not exist.

Runoff from Coso Wash, Renegade Canyon, and Mountain Springs Canyon ends up in Coso Basin (Figure 11). The inflow of ground water should be from 2,000 to 3,000 acre-feet per year and should not be saline. The southwestern end of Coso Basin may be subsiding rapidly enough in relation to Indian Wells Valley that the absolute elevation of the water table may lag behind what it would be in more stable terrain. The high salinity of the water in Coso Basin proved by the Airport Lake wells shows this water does not enter the China Lake Basin.

The alluviated region north of the axis of the White Hills comprises over 50 square miles and contains sediments to a depth of 4,000 feet or more. This area might be another storage basin from which water could be pumped in the future; however, we must determine the location and quantity of good-quality water.
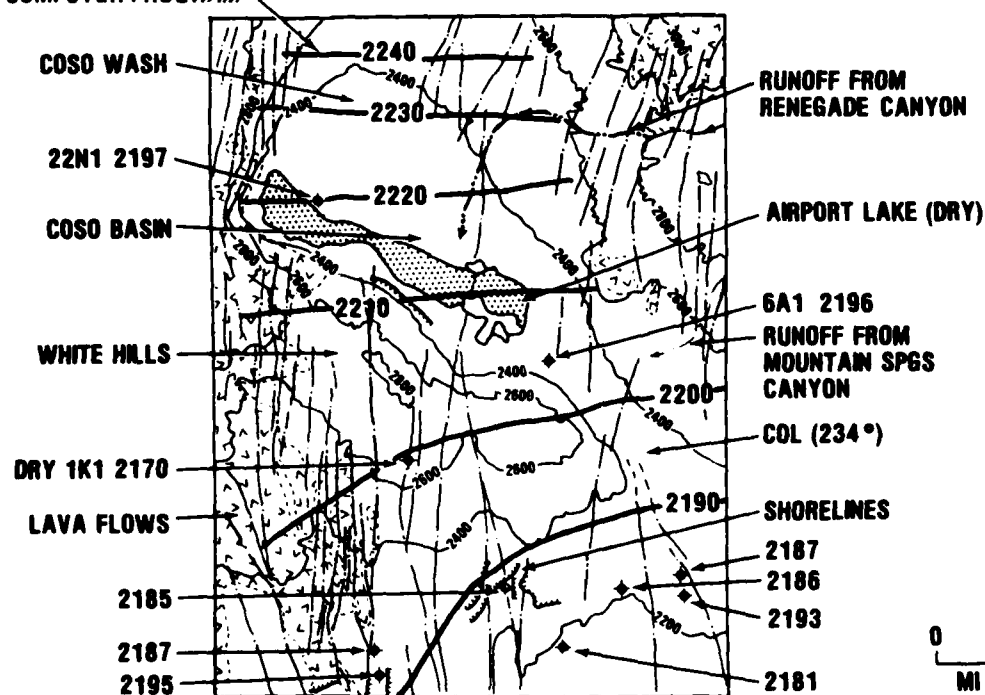
FIGURE 11. Locality Map for Airport Lake, White Hills, and Vicinity.* The bold lines and numbers represent the water-level contours in feet above MSL; the smaller, lighter numbers represent the land contours in feet above MSL.

* Figure 11 shows the water-level contours that are calculated by the mathematical model of Bloyd and Robson (1971) and are compared to the depth of water as shown in several wells. Wells 1K1, 6A1, and 22N1 show water at a considerably greater depth than the model indicates the water should be. The hydraulic gradient is only about 9 feet in over 8 miles. Considering the low transmissivity of the sediments, little or no water appears to be flowing from Coso Basin into China Lake Basin. If the water under Airport Lake is in a perched aquifer, the situation is even less likely to permit much flow.

In summary, we know little about the ground-water situation in the Coso Wash. We do not have a clear idea of what percentage of our water comes from the Coso Range, Renegade Canyon, or Mountain Springs Canyon. The only guides that we have are the ratios worked out by Bloyd and Robson, and these may not be correct in view of what information we have.

Water Migration. Water must enter from the north and east sides of the Valley because several thousand acre-feet are evaporated from the northern and easterly sides of the clay plug. Rather extensive north-south ground barriers produced by a series of faults discourage eastward migration of water from the western side of the Valley across the clay plug, to the northern and eastern sides of the playa. Transmission through the playa is not a very effective means of delivering water where it is discharged in the northern and eastern periphery of the playa. Another supporting consideration for entry of water from the north and east is the increase of discharge from 1913 to 1952 of some 690 acre-feet per year from the northeasternmost fringe of the clay plug. This discharge occurred in spite of the decrease in evapotranspiration of about 3,000 acre-feet per year from the basin as a whole between 1913 and 1953, presumably caused by interception of flow from the south and west.

GROUND-WATER EVALUATION BY MATHEMATICAL MODEL

The computer is a powerful tool in making assessments of hydraulic situations. A computer model can accurately describe the hydrology of an aquifer and can predict under a wide variety of pumping patterns the behavior of water-bearing formations. These models are in common use today to evaluate water supplies. Data from wells are incorporated into the model along with factors that describe the amount of water used and the amount replenished.

In the early 1960s the Naval Ordnance Test Station, now NWC, supported the United States Geological Survey (USGS) in preparing a mathematical model of the Indian Wells Valley water supply. Dutcher and Moyle made a conceptual model using the previous groundwork of Kunkle and Chase. This work, published in detail, was used by Bloyd and Robson, along with more current information, to form their two dimensional model of the water supply. Their results were published in 1971. NWC uses this model for planning purposes.

In making the model, the Valley is divided into squares, 1/2 mile on an edge. The intersections of the squares are called nodes. The water flow past each node is calculated on the basis of hydraulic gradient, transmissivity, and the input or extraction of water at each node.

The entire model is based upon the determination of the steady state condition of the aquifer in 1920-1921. The input of water to each node, around the edges of the model, was determined by empirically fitting the input in such a way as to reproduce the water table. The transmissivity was determined from well tests, then corrected as the effects of pumping at each node became clear. The discharge was calculated around and across the playa on the basis of depths to ground water and, consequently, evaporation rates. Allowances were made for changes in flow caused by ground water barriers as they were identified. An enormous amount of information was used to construct the model. The purpose of the model is to be able to predict the water table for a given pumping pattern.

The model can be used to make intelligent decisions about exploiting the water resources of the Valley. It is necessary to have accurate measurements of pumping rates and accurate forecasts of water usage at each node, but this is not always possible. Much pumping is not metered, and usage patterns change continually with the addition of new irrigation and housing projects. The model gives quite accurate forecasts of the configuration of the water table for any specified pumping pattern.

The model derives its strength from the corrections made to it from time to time as pumping rates change and the changes in the water table are observed. Such models are tautologies. They contain only what is put in, but they can be used to recalculate the input functions such as transmissivity, storage, and total water flow if the configuration of the water table is known. Models of this sort can be based on erroneous theory and poor data and still function well over a limited range of the variables involved. However, any departure from those ranges is potentially dangerous.

Bloyd and Robson estimated the total inflow in 1971 as 9,850 acre-feet per year. This is probably the best estimate of our annual recharge by means of flow calculations.

To improve the model, observation wells will have to be drilled around the northern and eastern sides of the Valley and in Coso Wash. The observation wells should settle the remaining questions about the recharge from these areas and bring the model into conformity with the observed water table. Lipinski of the USGS (1981) has proposed a 10-year program of data collection from the whole of the Valley, including the drilling of such wells. This effort is going slowly forward, with the support of the major local water users.

Within the state of the art, the model describes the situation and can be used for prediction- and decision-making purposes. This model is two-dimensional and fails to give, in three dimensions, the paths water takes to get to a certain point.

This means that, although quantitatively correct, this flow model cannot be used to handle some of the questions of chemical contamination without rewriting the model in three dimensions. When the 1971 model was developed, three-dimensional models were not available. They require more complicated programming and more stratigraphic information than currently is available. Chemical considerations limit the utility of the two-dimensional model in the exploitation of the aquifer, and a water quality model must eventually be developed for the area.

GROUND-WATER RECHARGE ESTIMATES

Assuming the ratios derived by Bloyd and Robson are correct, the Valley ground-water recharge estimates are shown in Table 4. These figures should be regarded as limits rather than definite recharge figures. Although questionable, the most reliable estimates of recharge to the Valley are based on underflow studies of the 1920-1921 water table because the water table had not been disturbed. Calculations based on transmissivities are questionable in a terrain as heterogenous as the Valley sediments, and calculations fail seriously when vertical and horizontal barriers to water flow, such as faults and confining clays, exist. Evaporation measurements are usually used in desert basins and, although imperfect, are the best indicators of discharge. The results of the underflow and the evapotranspiration calculations are not too different. The upper limit of Table 4 is derived from calculations that involve a questionable correction and is therefore too high. Data from

TABLE 4. Recharge to Indian Wells Valley
Ground Water in Acre-Feet per Year.

Determination	Sierra	Argus & Coso	Total
Computer model	6,680	3,168	9,850
Underflow (lower limit)	7,200	3,400	10,600
Underflow (upper limit)	11,000	5,200	16,200
Evaporative discharge	7,480	3,520	11,000

the computer study are probably more accurate because of the large amount of data going into the model and the computer's ability to calculate in great detail.

The recharge to the valley probably lies between 8,000 and 14,000 acre-feet per year. I will assume that the decrease in evapotranspiration between 1913 and 1953 is caused by pumpage and interception of water that would otherwise be evaporated and, hence, that the 8,000 acre-feet per year figure calculated for 1953 does not fully represent the recharge. I will use an average of 11,000 acre-feet per year as the recharge, although the actual figure may be a bit lower. *Using this estimate will not alter my conclusions much because the consumptive water use greatly exceeds the 11,000 acre-feet per year recharge estimate.*

PERENNIAL YIELD

The object of most ground-water studies is to find the perennial yield for an area. *The perennial yield is the amount of water that can be consumed in perpetuity without destroying the utility of the aquifer or without eventually depleting the water.*

The following measurements are considered in estimating the perennial yield: the water inflow, the amount lost to evaporation, and the amount exported from the basin. The inflow for Indian Wells Valley, the amount used by natural evapotranspiration, and the consumptive losses from the area have been estimated. *If we wish to maintain the safe perennial yield of water, consumptive use must be offset by an equivalent decrease in evaporation from the central Valley area.*

We receive an estimated 11,000 acre-feet annually of new water. If we adjust the pumping pattern to intercept 10,000 acre-feet of recharge, we can put into the water system almost as much water as evaporation wastes. A residual of water must be left for evaporation so water does not flow back from the playa to the wells. Even without the proposed pumping adjustment, evapotranspiration seems to have decreased from 11,000 to 8,000 acre-feet per year. *We can use 10,000 acre-feet per year in perpetuity, once evaporation from the fringes of the playa is reduced to 1,000 acre-feet per year, and water entering the Valley is captured for consumptive use.*

About 3,000 acre-feet of water evaporates each year from the area to the north and northeast of the clay body under China Lake playa. This water cannot flow across the numerous water barriers, including the clay body, to reach an area where it can be pumped with the present pumping pattern. It is impossible to reduce this evaporative loss without drilling new wells and removing the water from this part of the Valley. We cannot include this valuable amount of water in the perennial yield of the Valley unless the present pumping pattern is modified. This factor reduces the safe perennial yield, under the present pumping regime, to 7,000 acre-feet per year or less.

DECLINING WATER TABLE

We may not know the exact amount of water inflow, but we do know we are using more than we receive. This discharge is greater than the recharge.

Figure 12, taken from a USGS report by Mallory (1978), shows Dutcher and Moyle's (1973) construction of the water table as it was in 1920-1921. Very little water had been pumped then, so the figure is representative of the water table's pristine state. One small depression north of Inyokern and another southwest of what is now the China Lake housing area were the only notable regions of drawdown.

The dashed lines are ground-water barriers such as faults and other obstructions to the movement of water. The position of these obstructions varies slightly from map to map as published by the USGS. I have made the ground barriers the same in Figures 12 and 13 in order to facilitate comparison of water tables.

Figure 13 shows the water-table level in 1982. The whole water table has been lowered compared to the 1921 baseline. The position of the 2,200 foot contour is between 2 and 5 miles closer to the mountain edge of the basin in Figure 12 than in Figure 13. There is a severe drawdown in the Ridgecrest and Intermediate Well Fields. The Intermediate Field was pumped down to the 2,140-foot level in 1976 and pumping has continued. This 1976 level is lower than the water level in China Lake playa at 2,150 feet.
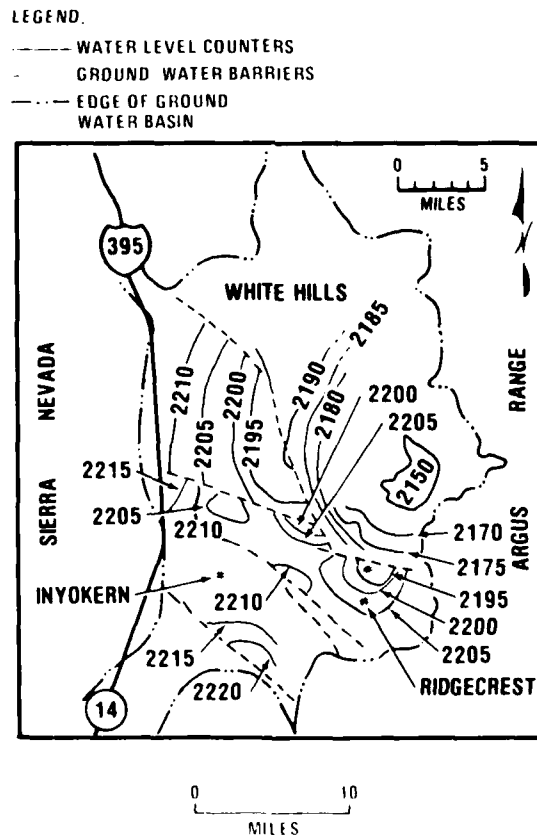
FIGURE 12. Map Showing Levels (in Feet Above MSL) of Ground Water in 1920-1921.
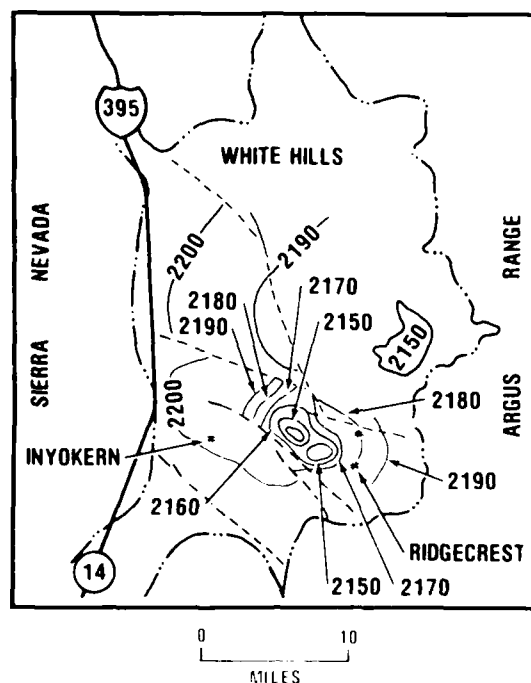
FIGURE 13. Map Showing Levels (in Feet Above
MSL) of Ground Water in 1982.

Wells are now spread throughout the Valley, except on the China Lake playa and the areas to the north and east thereof. Most pumping is done in two well fields, the Ridgecrest Field and the Intermediate Field. The latter is halfway between Ridgecrest and Inyokern. Considerable pumping is also done in the Inyokern area, but these wells are more widely spaced than in the two fields.

Most of the domestic water is taken from the narrow southwesterly trending strip between the two subparallel ground-water barriers. These barriers limit the recharge, and pumping is causing a large pumping depression in this area.

A ground-water deficit estimated at between 206,000 and 275,000 acre-feet developed from 1920 to 1976, an average overexpenditure of 4,900 acre-feet per year. This estimate is based on information from Figures 12 and 13, detailed maps from Dutcher and Moyle, and current water levels in Inyokern and in extreme eastern parts of the Basin. Water usage between 1912 and 1984 was 702,000 acre-feet, as shown in Table 5. This estimate is based on the USGS, metered pumping, acreage cultivation and crop type, and the number of people served by domestic wells and water companies.

The estimate of the amount of water pumped exceeds the water drawn from the aquifer. This difference is partially due to the capture of water that might otherwise have evaporated, inflow to the area of depression, return seepage of pumped water, and possibly the use of too low a coefficient of storage.

An estimated 1,370,000 acre-feet of the aquifer has been drained; this is equivalent to a 3.5-foot lowering of the whole water table from 1920 to 1984. Although the estimates are crude, they are the best that I can make from the available information. The estimates are good enough to point out a moral: *We are living beyond our hydrologic means.*

TABLE 5. Ground Water Pumped in Indian Wells Valley By Year.

Year	Pumpage, acre-ft	Year	Pumpage, acre-ft	Year	Pumpage, acre-ft	Year	Pumpage, acre-ft	Year	Pumpage, acre-ft
1912	2,000	1950	6,000	1960	10,600	1970	14,000	1980	26,500
1919	2,000	1951	6,500	1961	10,300	1971	14,300	1981	...
1942	2,300	1952	7,200	1962	11,000	1972	15,200	1982	...
1943	2,800	1953	8,200	1963	11,000	1973	14,900	1983	
1944	3,200	1954	8,400	1964	11,600	1974	14,400	1984	29,500
1945	3,600	1955	9,000	1965	11,600	1975	14,500		
1946	4,200	1956	9,400	1966	12,400	1976	14,100		
1947	4,600	1957	9,400	1967	12,300	1977	...		
1948	5,000	1958	9,400	1968	13,000	1978	....		
1949	5,600	1959	10,000	1969	13,500	1979	23,600 (est)		
TOTAL	91,300		174,800		292,100		445,300		702,000 acre-ft as of 1984

WATER USE VERSUS AVAILABILITY

Between 1953 and 1959, we began to use more water than was perennially available. Figure 14 shows the estimated water usage in the Valley since 1920; in addition, Figure 14 shows projected estimates to 1990. My estimate is based on a population growth of about 2% per year, while the other is the estimate of the USGS, which I thought to be a little high but reasonable. Indian Wells Valley population is exceeding both these estimates and showing every sign of continued growth. Population growth is now approaching 10% per year.

In 1912 eight wells were operating in the Valley with a total pumpage of 2,000 acre-feet per year. By 1920 water use was still 2,000 acre-feet per year, when 800 acres were under cultivation. Although the number of wells drilled in the Valley increased until 1929, no data are available from 1920 through 1941. From then on, the pumpage has been estimated by the USGS from the records of metered wells, counting the unmetered wells, and estimating the usage on the basis of type of cultivation and number of people using the water. The figures are probably low because some wells have escaped notice.

The estimated evapotranspiration is taken as 11,000 acre-feet per year in 1920 and 8,500 acre-feet per year in 1953; from then on there is a decrease in proportion to the usage. New surveys of the evapotranspiration should be made every few years. My estimate may be high. The estimated recharge is taken as a constant 11,000 acre-feet per year. The total discharge, the rate at which the Valley is losing water to the atmosphere, is the sum of the consumptive usage and the evapotranspiration. Figure 14 ignores a small recharge to the ground-water table by seepage of sewage, irrigation water, etc.

The consumptive water use and evapotranspiration shown in Figure 14 now seem too low in view of the amount of water used in 1979. The principal water users, all of whom meter their pumping, were contacted to obtain the 1979 figures. Small water companies providing water to households and water pumped by individual well owners were estimated and may be low. The agricultural pumpage was determined by multiplying the acreage solely in alfalfa by the consumptive use year around for that crop. No attempt was made to account for orchards and gardens. These values are shown in Table 6. The recharge may be as high as 11,000 acre-feet per year and the discharge may have dropped to 6,000 or 7,000 acre-feet per year.
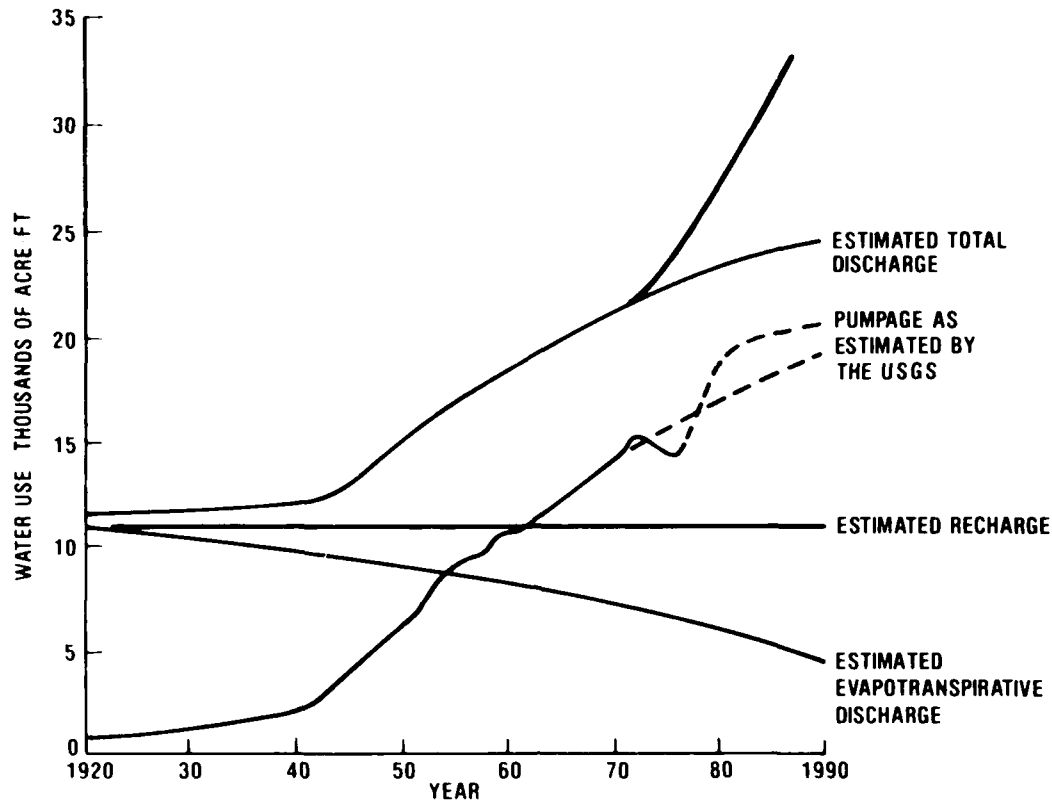
FIGURE 14. Estimated Water Use, 1920 Through 1990.

TABLE 6. Acre-Feet of Water Pumped in 1980 and 1984 *

Producer	Pumpage, acre ft	
	1980	1984
Wilbur Stark Water Co	993	1,700
Naval Weapons Center	5,370	4,200
Indian Wells Valley Water District	3,402	4,400
Searles Valley Water Users	3,100	3,100
Antelope Valley Water Co	429	500
Householders (estimated)	500	600
Agriculture (estimated from alfalfa acreage)	9,700	12,000
Sawmill	3,000	3,000
Total pumpage	26,494	29,500
Discharge from the playa	8,000	8,000
Recharge	11,000	11,000
Agricultural seepage returned	2,000	
Deficit	21,494	26,500

* Values in Table 6 for 1980 were estimated by St. Amand; values for 1984 were estimated by Decker and Lee. Both sets of data are probably underestimated.

Actual water use, much higher than anticipated, is shown in this table. The amount of water used has risen faster than the population has increased. NWC employees moving off the Center have caused some of the increase because of larger home lots and more enthusiastic landscaping.

Water usage has increased since the original manuscript was prepared in 1980. In 1984, independent of one another, Dr. Donald L. Decker, an NWC physicist, and Mr. Jeff Lee, a local news reporter, reestimated the consumptive use of water. I checked their calculations. The consumptive use of water rose from 26,500 acre-feet in 1980 to 28,000 acre-feet in 1984. The overall deficit in the water budget is increasing about 6% per year; in 1980 it was 21,494 acre-feet, and in 1984, it was 26,500.

Figure 15 is a combined flowchart and schematic summary estimating the water budget of Indian Wells Valley as of 1979. The total inflow is postulated as 11,000 acre-feet. The amounts from each source area, modified from Bloyd and Robson and adjusted to total 11,000 acre-feet, are based on an altitude-area relationship and are probably proportional to the amounts received.

Item "a" is runoff from the whole of the surface. In most years runoff is zero, although during flood years, runoff may be quite high. The runoff contribution to the water supply is unknown. Item "b" is seepage from domestic uses such as lawns, cesspools, gardens, leaky pipes, etc. Item "b" is small compared to the total pumpage. The diagram depicts only known, proven sources.

Figure 15 is useful for estimating the possibility of changing water use. For example, the 1,700 acre-feet of sewage water that now evaporates could be reclaimed and sent to Searles Valley for industrial use or irrigation. Reclamation would reduce the 400 acre-feet of this water currently seeping into the shallow aquifer each year.
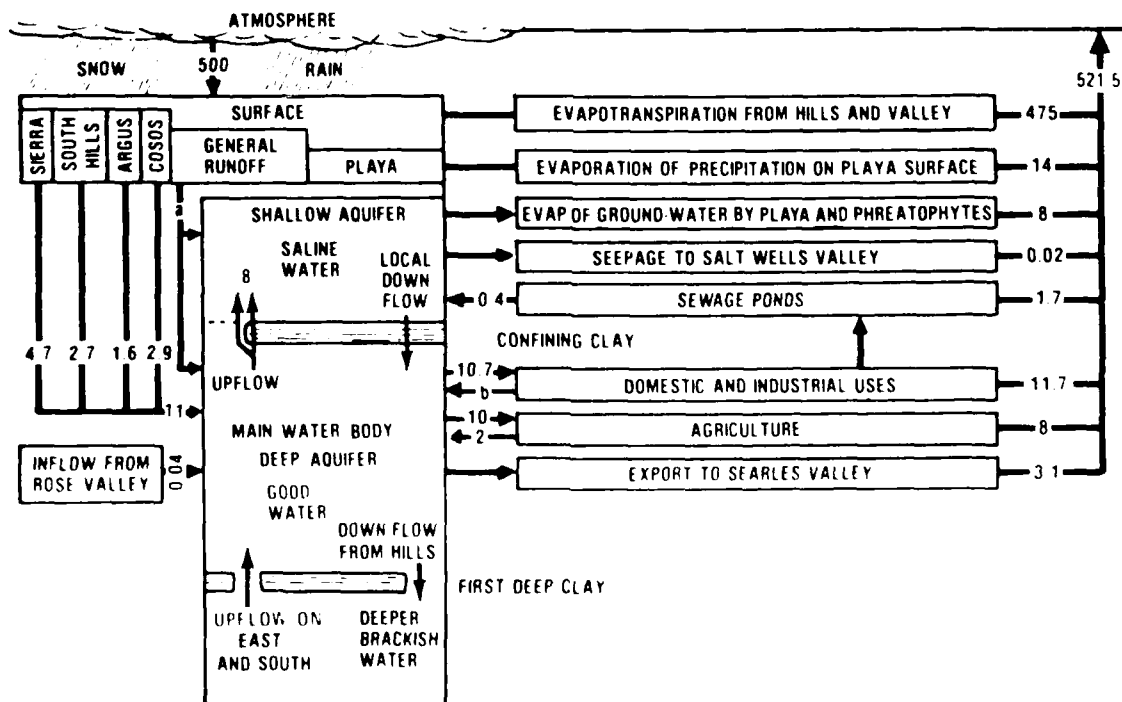
FIGURE 15. Water Budget and Flowchart

SEDIMENTATION IN THE VALLEY

Indian Wells Valley is filled with sediments and their decay products from the surrounding hills. A wide variation in sedimentation exists across the Valley. A cross section of the Valley is shown in Figure 16. Near the hills, the material is coarse and contains boulders and large stones that decrease in size toward the center of the Valley where the material is extremely fine. Mud flow deposits extend into the Valley. Fine material from the Owens River is interfingered with detritus from the hills.

Beds of tight, impermeable clays, relics of ancient lake bottoms more extensive than the present playa lake, are found at several depths. The upper blue-white clay bed is about 300 feet below the present surface. This clay bed is a seal between water above and below. Water has been pumped from the deposits above the blue-white clay layer, reducing hydraulic pressure on the layer and thereby permitting water from the more saline aquifer beneath to migrate upward. The clay is not permeable; and although some water comes up through the clay itself, the water moves up around the edges and through fractures, cracks, clastic dikes, and discontinuities in the clay bed or beds. The effect is thus quite spotty and is analogous to salt water intrusion encountered near a seacoast, where fresh water is found floating on salty water. Local well drillers are careful not to drill domestic wells through this layer; if the drillers puncture the blue-clay layer, they usually seal the well at the puncture.

A plug of poorly permeable clay in the central and eastern parts of the Valley, called the "confining clay," discourages the movement of water upward through it. Thus, water seeking its own level is prevented from freely reaching it, as shown in Figure 16. Artesian wells exist near the former Paxton Ranch (Photo 11) and elsewhere on China Lake playa. Some deep wells in the playa have water levels above the land surface; whereas shallow wells have water levels below the surface at the same location.

FIGURE 16. Schematic Cross Section Showing Sedimentation

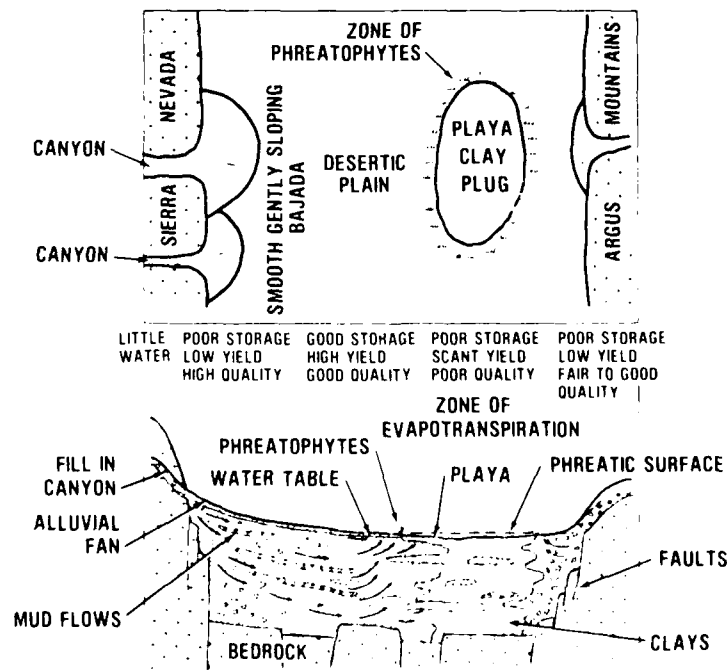PHOTO 11. Artesian Well at Paxton Ranch. Perennial waterflow has allowed grasses to grow. Deep well on the playa shows phreatic head above ground level.

STORAGE COEFFICIENTS AND SPECIFIC YIELD

The amount of water stored in the sediments depends upon the amount of open pore spaces in the sediments. These holes or pores among rock grains contain water when the rocks are saturated. *The ratio of empty space to volume of rock is called porosity. Not all the water in the pores can be recovered because some clings to rock grains.*

The ratio of the volume of recoverable water to that of rock is called specific yield. The ratio of the volume of water that remains to the volume of rock is called the specific retentivity. These factors define how much water can be recovered from a given volume of sediments. Usually, the ratio of the drawdown to the pumping rate is used to estimate the storage coefficient or specific yield. This method is not exact. Measurements of gravity permit a determination of porosity even when the rock is saturated. Values determined by wells run as high as 0.25, or a little more. Values determined by gravity studies indicate storage capacities as high as 0.35 in places (Zbur, 1963).

The specific yield is low for the coarser rocks near the hills; the available pore space is less than in finer sediments because larger boulders do not have many interconnected holes. The storage coefficient of sediment near the hills is about 0.001 to 0.1. The sediments yield water to wells, but the specific capacity is low and the local drawdown during pumping is large.

A little farther from the hills, where the boulders are smaller, fewer, or nonexistent and the sand grains are large and well sorted, the porosity, and hence the storage coefficient and the specific yield, is higher and the specific retentivity is low. The aquifer is best where the sand grains are about the same size, and are large, clean, and rounded. Here, the storage coefficients are between 0.1 and 0.35. The specific capacity is high, drawdown from pumping is low, and wells produce water freely.

The specific retentivity is high in the clays. The storage is low and wells do not produce much water unless they happen to penetrate a sand or gravel lens. The quality of the water

in the blue clays is usually poor; in the brown clays it is often good. Obviously the best site to drill a well is into the desertic plain zone, but the area near the hills is also good.

WATER STORAGE

To calculate the amount of water stored in the Valley, Dutcher and Moyle divided the Valley containing useful, pumpable water into three storage units, each having common properties. These three storage units, shown in Figure 17, occupy only about 25% of the Valley's area. The details of these units are given in Table 7. A large amount of water is stored in the Valley. Dutcher and Moyle base their calculations on the water contained in the upper 200 feet of saturated deposits below the surface. Water exists below this level, but for various reasons, pumping this water is not now currently practical. Not the least of these considerations is the cost of pumping. The most important consideration is that if the water table is lowered by 200 feet, chemical contamination will render the aquifer useless. The amount of water stored in the Valley, even the amount indicated in Table 7, cannot be recovered by means of the present pumping pattern. Table 8 shows a more pessimistic, but perhaps a more realistic, appraisal of the available useful water under the present regime.

Although the surrounding hills contain a certain amount of crushed rock, and some fault zones contain a considerable quantity of water, the granitic mountains are not a source of large amounts of water stored in the rock body and potentially available to the Valley users during dry years.

By 1995 most of our water now in storage will be worthless because the system will be irreparably damaged. Two factors will be responsible: the inceased usage rates in the recent past and the extrapolated increase for the future at 9% per year. Although some good quality water will exist, it will be extremely hard to pump. The water table will be lower throughout the basin than the level of the salty water in the upper aquifer. The amount of water
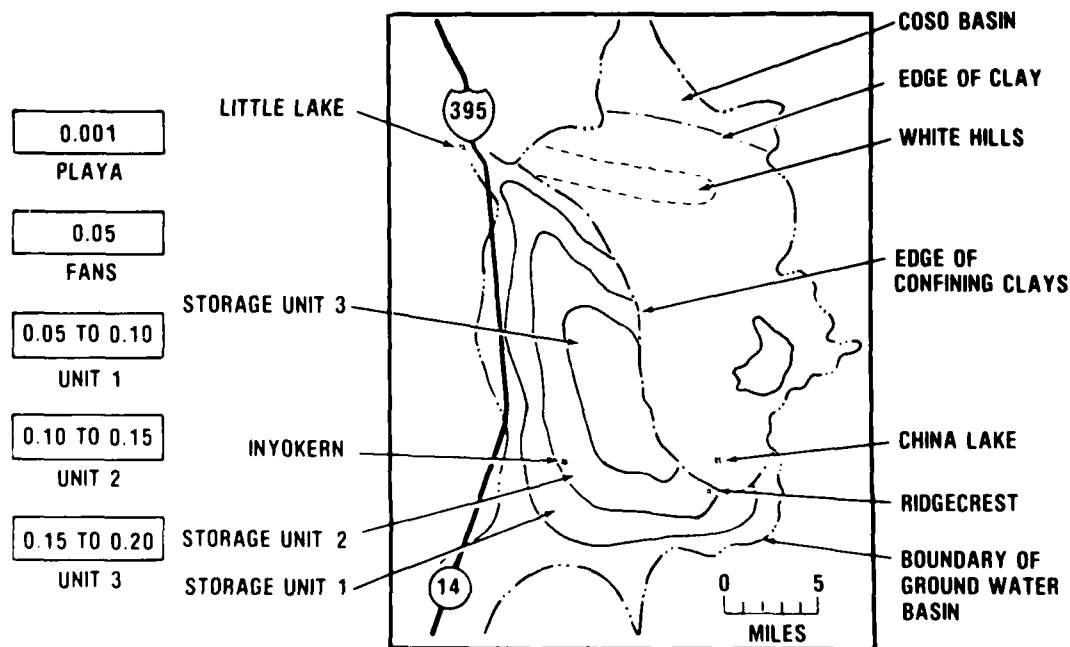

FIGURE 17. Storage Areas in Indian Wells Valley.

TABLE 7. Water Storage Based on 200 Feet of Useful Water
Availability, as of 1973.

Storage unit	Areas, acre-ft	Saturated volume, acre-ft	Specific yield, %	Storage, acre-ft of water
1	21,800	4,360,000	10	440,000
2	19,500	3,900,000	15	580,000
3	29,500	5,900,000	20	2,180,000
TOTAL	70,800	14,160,000	. . .	1,200,000

TABLE 8. Water Storage Based on Useful Water Above
2,150 Feet MSL, as of 1973.

Storage unit	Areas, acre-ft	Useful depth, ft	Saturated volume, acre-ft	Specific yield, %	Storage, acre-ft of water
1	21,800	60	1,308,000	10	130,800
2	19,500	55	1,072,500	15	160,875
3	29,500	50	1,475,000	20	295,000
TOTAL	70,800	55	3,855,500	15.5	586,675

available will then decrease rapidly in proportion to the decreased permeability of the sediments at depth and, consequently the chemical content of the remaining water will deteriorate further throughout the basin.

WATER QUALITY

Storage Units One and Two

Well water in storage units one, two, and three is usually excellent, except on the extreme south and southeast of the Ridgecrest area. This water, except in a few places, is fresh from the hills, and is moving toward the Valley's center. The water contains about 300 parts per million (ppm) of dissolved solids, usually sodium chloride and, perhaps, a little sodium carbonate. Not only are the wells in storage areas one, two, and three the most productive, but the water quality is high.

Clays

Water in clays and on the playa contains many chemicals. Salt, sodium carbonate, borates, sulphates, etc., reach levels of 1,000 to 14,000 ppm. In the shallow part of the aquifer, these salts are continually being concentrated by evaporation. Since water containing 500 ppm has evaporated from the surface for at least 5,000 years, to an average depth of 0.3 feet per year, some 1,000 feet of water have evaporated and about 925 tons of salt per acre have concentrated in the area. This low-quality water is found over most of the China Lake playa and is also found in many of the clays at depth. One often hears the false statement that the arsenic content of the water is high. In only a few places is arsenic found, and the domestic water has only the slightest traces. Some arsenic, 0.02 ppm, has been reported from the southeast corner of the Valley.

The Navy has sunk test wells at several levels to determine water quality, but not enough sampling has been done to assess the quality of water at depths from all over the Valley. Figure 18 shows a generalized concept of the variation of dissolved solids with depth.

Water beneath the blue-white clay at about 300 feet is markedly more saline than the water above. The salinity varies from place to place, but is high enough to be only marginally useful for domestic purposes or agriculture. This underlying salty layer is a potentially serious trouble source and places a limit on the amount of useful water stored in the Valley (Photo 12).
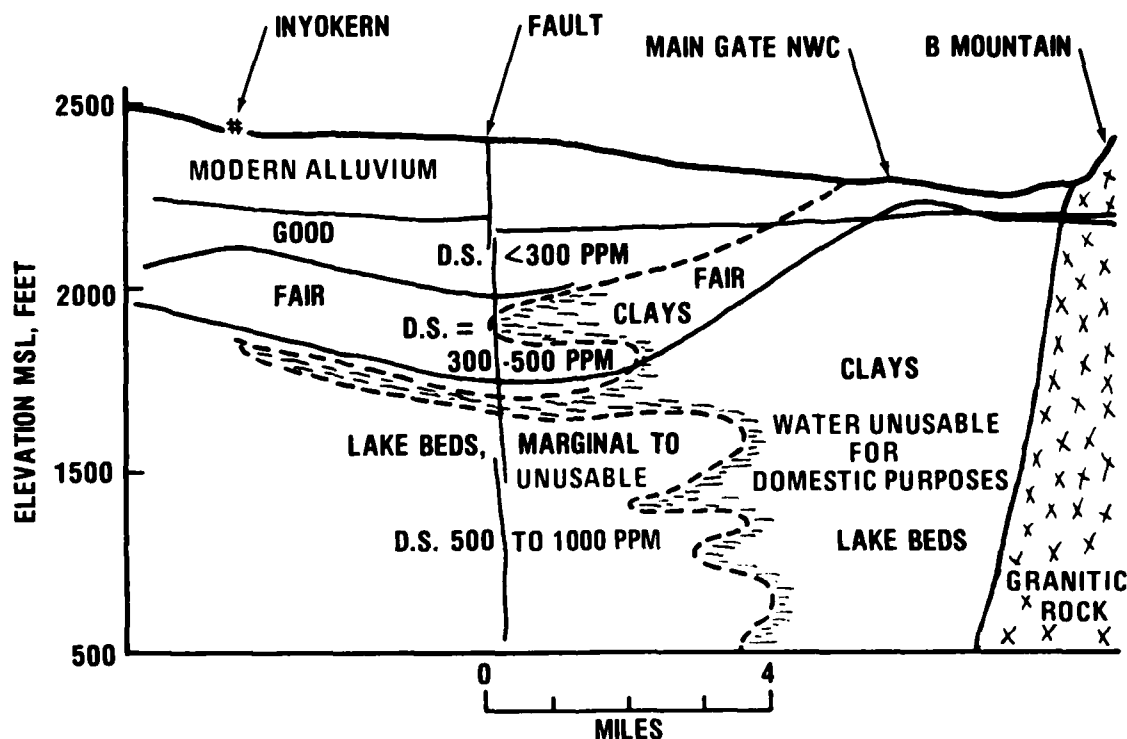

FIGURE 18. Water Quality As a Function of Depth. Dissolved solids (DS).

PHOTO 12. Dr. Roland von Huene Examining Salt Crust on Ground Water In a China Lake Playa Crater.

Shallow and Deep Aquifers

The USGS defines the shallow and the deep aquifer in terms that are important for the computer model. The shallow aquifer is defined as the water in and on the "confining" clays of the China Lake plug; the deep aquifer is the main aquifer from which our water is drawn. The USGS shallow and deep aquifer definitions have implications for water quality in the good aquifer.

Usually, water seeping up around the edges of the clays is driven through the clays, or through cracks in them, by hydrostatic pressure. Thus water coming from the deep aquifer reaches the surface, where it is evaporated. Enough of this surface water has evaporated in times past to concentrate salts, and freestanding water on or around the playa is usually useless.

If for some reason, such as lowering of the water level elsewhere in the Valley by pumping or by an accumulation of water in the upper aquifer from lawn watering or sewage ponds, the hydraulic gradient is reversed, saline water will be pushed from the upper levels to the lower. Under the present regime, this will happen soon and should be avoided if possible.

Figure 19 is adapted from the latest data made available by Lipinski of the USGS. The light lines represent flow lines for underground water that flows at right angles to the water-level contours. The dividing line separates the northeasterly flowing water from the southerly flowing water. This line is known as the China Lake Ground-Water Barrier. The exact nature of this barrier is not known. Some hydrologists think the barrier may be a fault, but the barrier may just be a thick septum of clay that does not reach the surface.

The area around the China Lake community shows a ground-water high, possibly due to watering of lawns, or possibly due to leaking water pipes. This ground-water ridge furnishes, or acts like, an hydraulic barrier—currently preventing the flow of very saline water from the area north of the China Lake community into the Ridgecrest depression. The ground-water barriers to the west limit the rate of recharge of the Ridgecrest and Intermediate Fields.

Water from the south and east is now flowing into the Ridgecrest and Intermediate Fields. This water is highly saline and contains boron, some arsenic, and a good deal of carbonate. Unless something is done soon to relieve the depression in the ground-water surface, the Ridgecrest Field, and subsequently the Intermediate Field, will become unusable.

CHEMICAL CONTAMINATION

Migration of Saline Water From China Lake Playa

Two problems with chemical contamination now exist. In one type of problem, water migrates horizontally from one area to another. This means contamination might occur if so much water is pumped from the Ridgecrest and the Intermediate Well Fields that the water flow from the main body to the China Lake playa reverses and saline water flows into the pumping fields. This process can be predicted by means of the USGS model. *Flow reversal will begin within a decade unless the pumping pattern is changed. This is a serious matter, but enough time remains to correct the pumping pattern if we are willing to insist upon, and pay for, sound water management.*
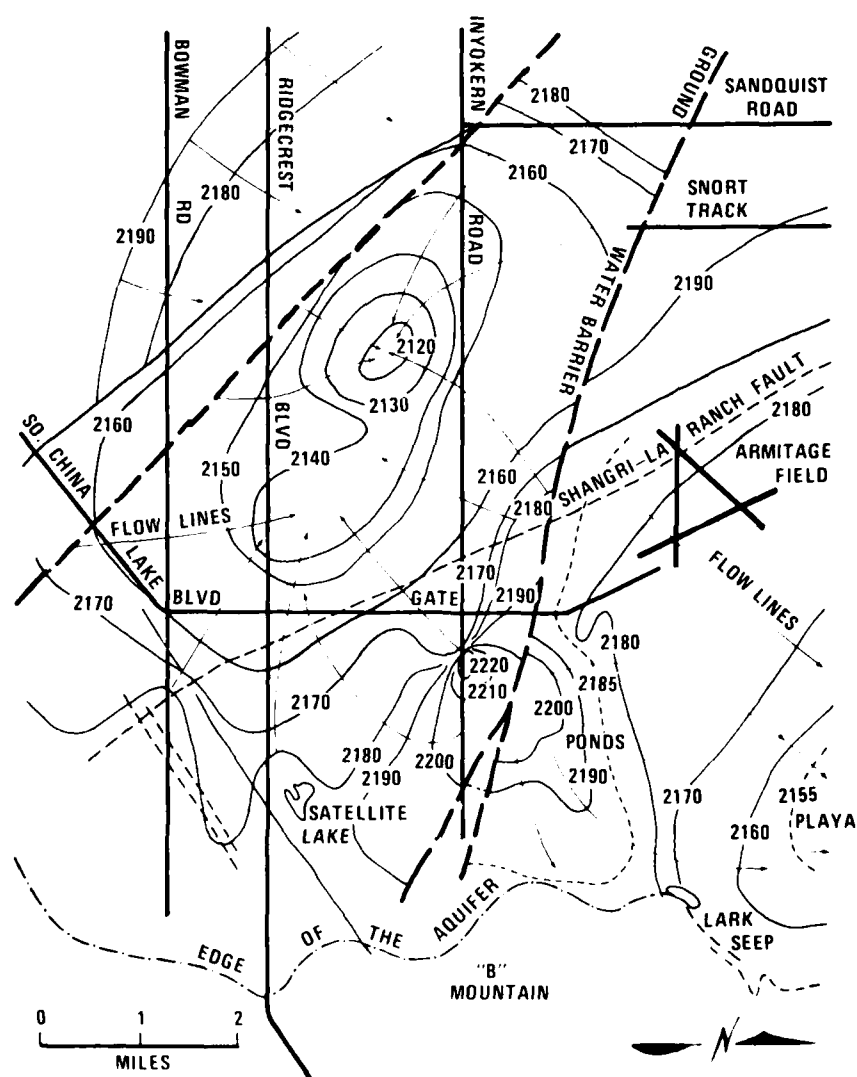
FIGURE 19. Water-Flow Lines. The light lines represent flow lines for underground water that flows at right angles to the water-level contours. The numbers show the water-table level in feet above MSL.

Vertical Migration of Saline Water From, Through, and Around Clays

The other type of problem is caused by intrusion of the saline water from below the blue-white clay. This intrusion is causing difficulties in private wells on the south and east sides of Ridgecrest, where the chemical content of a number of wells is increasing. Some of this water was poor to begin with and is rapidly becoming useless. Boron, chlorides, sulphates, etc., are present in increasing quantities. As near as I can tell, the water quality of the main NWC system and of the Indian Wells Valley Water District is not yet deteriorating. Three-dimensional models to describe these situations have been developed for water systems elsewhere and can be applied locally, but only at considerable expense.

EFFECTS OF PUMPING ON LAND SURFACE

The sediments from which water is pumped have dried out. These sediments contain clays and other fine materials that tend to retain the water and lose it slowly. Once dried out, these sediments shrink. If the sediments become wet again, they swell. Shrinking and/or swelling materials cause changes in the surface topography that are evident as fractures in building foundations and walls, in sidewalks, parking lots, and other paving. Cracks have begun to appear in Ridgecrest and portions of China Lake. Similar cracking is notable in Inyokern on the airport aprons, and in protected areas such as underneath buildings. The distortion, currently just a nuisance in Indian Wells Valley, will become more serious unless the pumping pattern is changed. This distortion, according to some opinions, may be tectonic, but the pattern and locations of cracking makes this unlikely.

Surface distortion can be serious. For example, long gaping cracks have appeared in fields near Cantil because of heavy consumptive use of the local ground water. These cracks have damaged roads and buildings.

EFFECTS OF DESICCATION ON CHINA LAKE PLAYA

As the surface of China Lake dries out, the wind dislodges sand and silt. At least 10 feet of such material has been stripped off the lakebed since the lake dried out after the Little Pluvial about 3,000 years ago. The sands were deposited on the Coso and Argus Ranges, where they are now seen as light colored blankets over the low hills and in the canyons. The surface material in deflational areas is usually removed down to a layer of stable clay. The surface of the clay is covered partially with remnants of the original sediments, with small sand dunes composed of the larger particles.

Where the clay layer is exposed and is close enough to the ground-water table, water is carried by osmosis and capillarity to the surface, where the water evaporated and any dissolved solids are deposited as crystals. The growth of the crystals produces a puffy efflorescence in the surface layers, and the otherwise quite stable clays are then subject to removal by the wind.

This process of desiccation and deflation is natural and cyclical. Evaporation lowers the water table; and a lower water table makes more sand and silt available for removal by the wind. This process is something that we will have to live with unless some means for stabilizing the surface can be found (Photo 13).

WHITE H

LAVA

LAKE SEDIMENTS

GRANITIC ROCKS OF COSOS
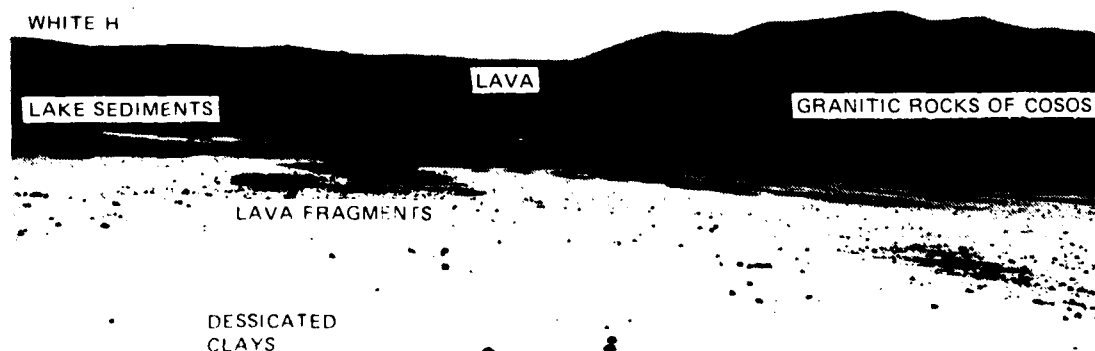
LAVA FRAGMENTS

DESSICATED
CLAYS

PHOTO 13. Close-Up of Airport Lake Showing Dessicated Cracks in Clays. Lava pieces on the playa surface indicate lava flows over crushed granitic rocks.

A related problem arises from cultivation of the desert. Once the native plant cover is disrupted over a large area, vegetation reestablishes slowly, if at all. Farms in the north central part of the Valley, abandoned in the 1920s, left nothing to protect the soil from wind erosion. Creosote bushes, once torn out, do not reestablish easily. Russian thistle (*Salsola*) will grow for a time on the disturbed ground but eventually it, too, gives up.

Intensive agriculture, practiced in many desert basins, is eventually abandoned when the ground-water table is lowered to where pumping becomes uneconomical. Abandoned farm sites remain a source of windblown dust for decades thereafter.

WATER MANAGEMENT

This section sets forth some ideas originally stated by others, including Moyle, Dutcher, Kunkle, Chase, Lipinski, S. D. Elliot, C. F. Austin, W. C. Bonner, von Huene and W. Stark. Most of the suggestions are in use elsewhere in the world. These suggestions are repeated here so decision makers can be reminded of the opportunities open to them.

SOUND PUMPING PATTERN

The present pumping regime is causing excessive localized water level decline, is endangering the aquifer by inviting chemical contamination, and is causing considerable hardship to private well owners. The problem is how to ensure a satisfactory water supply for the heavy users, such as Ridgecrest, China Lake, and Trona, where individual wells are not practical, while minimizing damage to privately owned wells and small water companies. The community will benefit in future years by continuing the use of private wells because the pumping depression will be more evenly spread over the whole Valley. Long water mains, built at exorbitant expense, will not be necessary to service areas that can be better serviced by individual wells or by small companies. The large water users should consolidate their systems to bring about an economy of scale and to capitalize the system.

West Side

Most water comes into the Valley from the Sierra Nevada. The ground-water table, though deeper, is slightly topographically higher near the mountains than it is further east. The natural flow of the water from the mountains to the playa can be interrupted in the desertic plain to the east of the railroad tracks that run north from Inyokern. Storage and pumping characteristics are excellent in that part of the Valley. For these reasons a line of wells, shown in Figures 20 and 21, spaced at 1/2-mile intervals, should run northward from the Inyokern Road to the vicinity of the sawmill, along a line subparallel with the railroad tracks, but just far enough east to avoid interaction with private wells west of the NWC boundary.

Wells along the northward line should be selectively and carefully pumped to bring about a gradual and uniform depression to an altitude about 10 feet in excess of the altitude of the saline water on the periphery of the China Lake playa.

While the water table between the wells and the Sierra would drop slightly, the major modification of the water table surface would take place on land now held by the Navy and
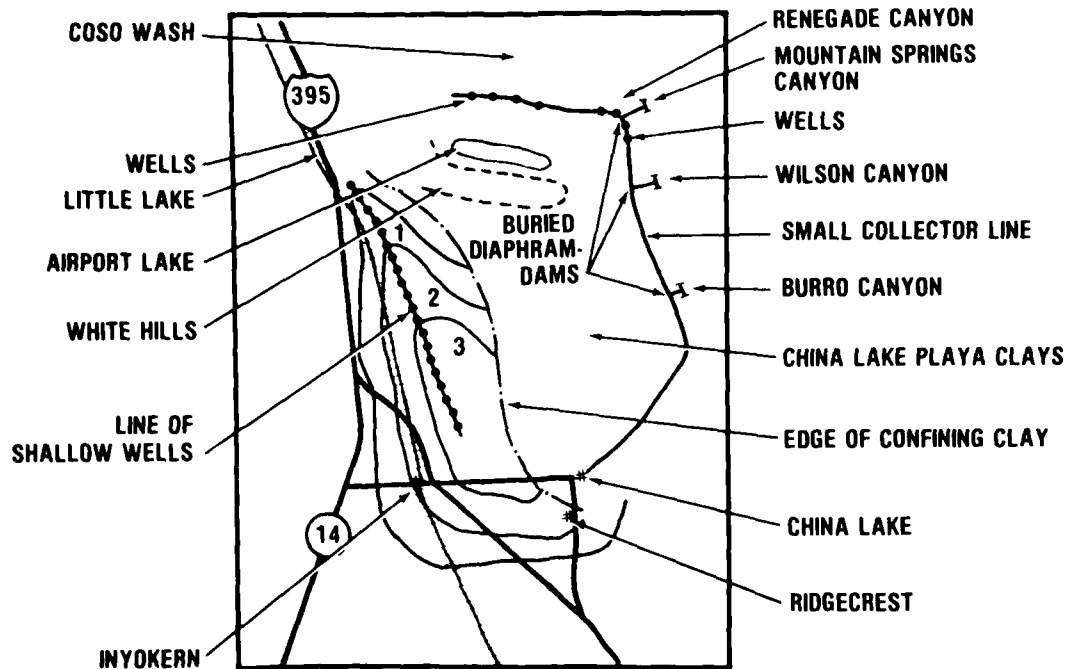
FIGURE 20. Optimum Pumping Pattern.

would not gravely affect private landowners. Careful operation of this well-field complex would systematically decrease the evapotranspiration from the western sides of the playa clays and thus increase our available water in an environmentally sound and cost-effective manner.

If commercial pumping of evenly spaced wells is concentrated north of Inyokern Road, some recharge will ultimately reach privately owned wells in the Inyokern, Intermediate, and Ridgecrest areas.

The pumping pattern described above will assure a continued supply of high-quality water with minimal effects on the aquifer and the least disruption to those who, because of cost and distance, cannot afford water from one of the major producers.

North and East Sides

There is a possibility of developing some 3,000 acre-feet per year more water by capturing the recharge from the Coso and Argus Ranges. A systematic program of exploration should be carried out soon to define the extent of this resource, test the water quality, and determine the specific capacity of wells in this area. If this water resource should prove out, then we should consider installing a pipeline to bring that water into the system. A pipeline would help by developing access to more stored water and would prevent the evaporative loss of about 40% of our annual recharge. A pipeline along the front of the Argus Range with wells in the mouths of Burro Canyon, Wilson Canyon, and Mountain Springs Canyon, arriving westward across Coso Wash at about the 3,000 foot contour, would bring the water south by gravity flow. Indeed, buried diaphragmatic dams in the canyons could be used to collect the water without pumping.

FIGURE 21. Integrated Water System for the Indian Wells Valley.

ECONOMIZING ON WATER USE

Loss of Water From Sewage Treatment

Ridgecrest and China Lake have a combined sewage treatment facility, managed by the City of Ridgecrest, located on the old China Lake bed. The treated water is evaporated from large sewage ponds. Some of the water seeps into the ground.* The loss of water by evaporation from the present sewer ponds is an uneconomical use of water. Seepa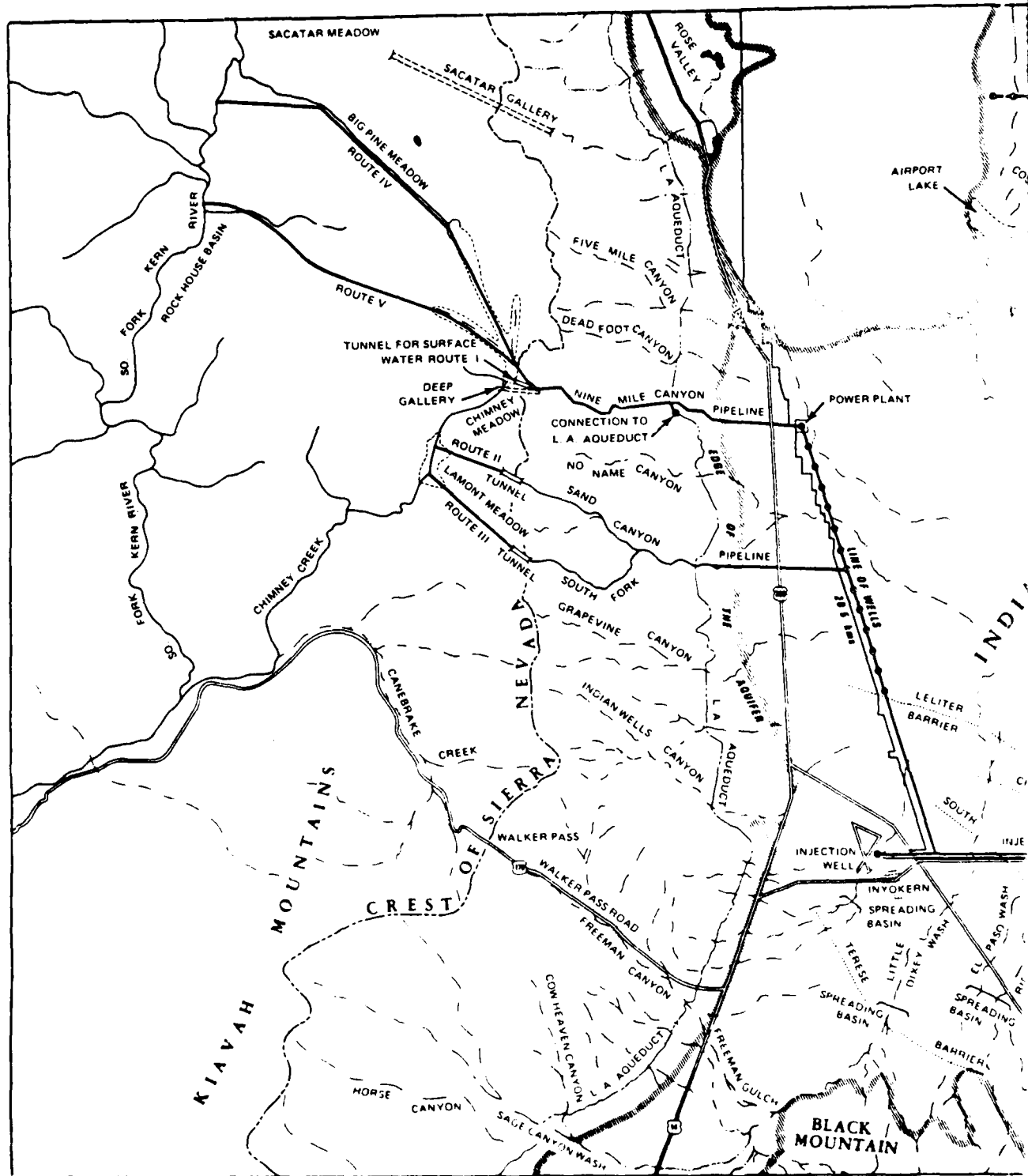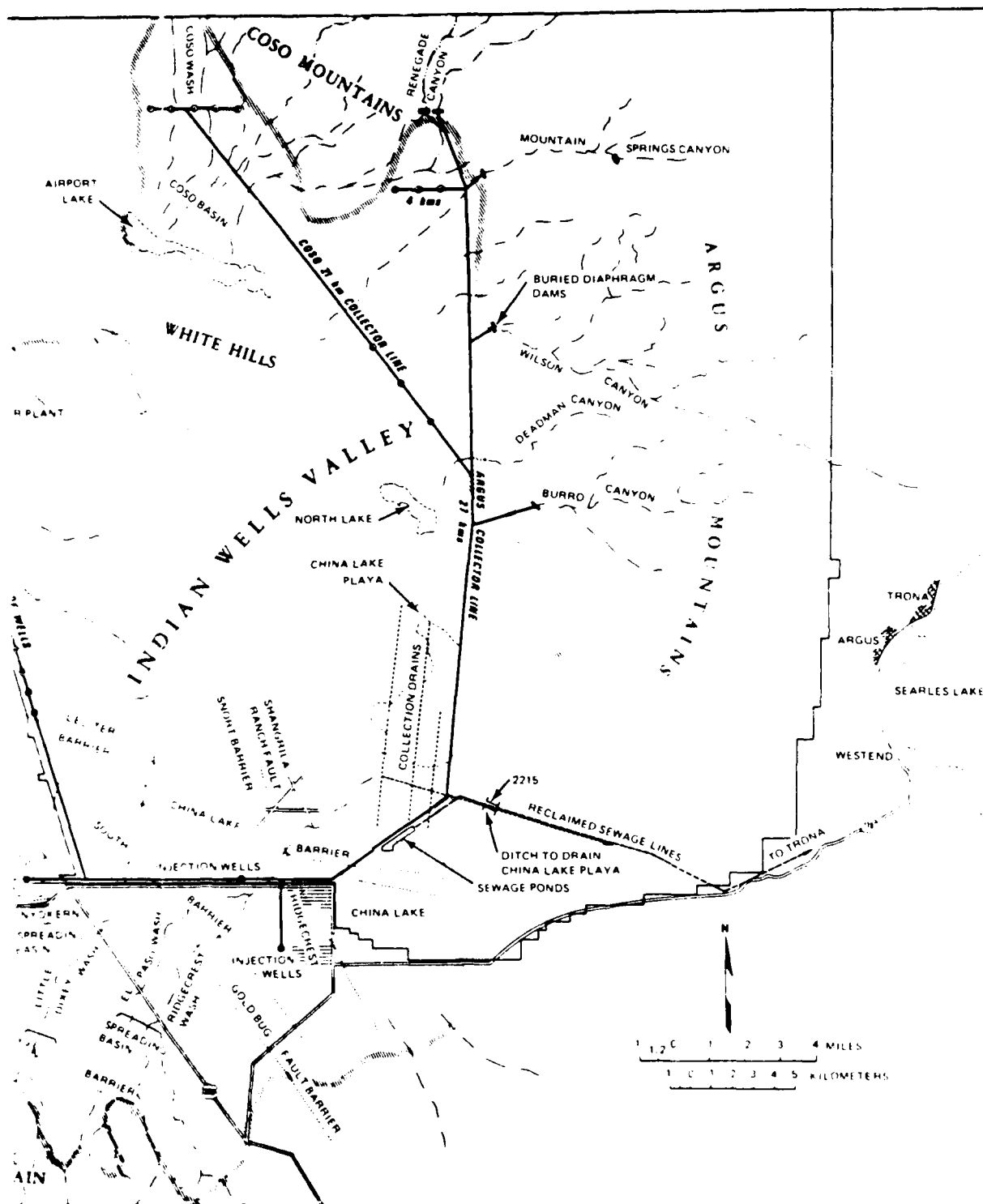ge from the ponds is raising the water table locally and will eventually aggravate contamination problems by forcing salty water from the so called "shallow" aquifer down and out into the good water below and to the south.

Treated sewage water could be made available to the chemical industry in Searles Valley for use as plant process water so that the withdrawal of fresh water from Indian Wells Valley would be reduced by an equal amount. Treated sewage water should also be used for irrigation or similar purposes. This water could be further treated, as necessary, and then injected into the aquifer for storage and eventual reuse. This water, injected into the ground between the so-called saline upper aquifer and the Ridgecrest pumping depression, would create a hydraulic barrier to prevent invasion of the lower aquifer by salty water from the upper aquifer on and around the China Lake playa. This barrier could be an effective means of stopping the movement of contaminated water from the playa into the main water source of Ridgecrest. Similarly, but at great cost, such a barrier could be constructed on the western side of the playa, if necessary.

Community and Agricultural Water Use

Whole books have been written on how to economize on water use. Many options are available to individuals and to the community as a whole to decrease the use of water without interfering with the quality of life. None of these options are being seriously practiced by other than a few scattered individuals. Cultivation of lawns should be stopped. Design of new homes should include passive cooling so that water used for evaporative coolers could be sharply reduced.

Large scale agriculture involving crops with annual water requirements of over 2 to 3 acre-feet per acre should not be practiced locally, unless supplementary water sources are identified and used. Advice and counsel should be sought from specialists in desert land agriculture. The Arid Lands Institute of the University of Arizona has such talent available, and the Israelis have had stunning success in desert farming. An example that might well be practiced here is changing from the cultivation of alfalfa to the cultivation of *Salsola*. *Salsola*, also called Russian thistle and tumbleweed, is excellent fuel and can be grown commercially to make fireplace logs. A greater profit can probably be made in this Valley with tumbleweed and 10 inches of rain or irrigation than with alfalfa and 10 feet of water. A unified approach to this problem would yield immediate results and be of benefit to the Valley as a whole.

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* Although the sewage ponds have always seeped water to some extent, the newer ponds are now leaking about 1,500 acre-feet of water per year to the saline upper aquifer. The city of Ridgecrest (as of February 1985) is taking steps to correct the situation.

We are presently consuming about 600 gallons of water per person per day. This estimate includes the water exported to Searles Valley. We could get by on much less. Without local farming, we would use about 350 gallons per person per day; we could get by comfortably, but not spashily, on 50 gallons per person per day. If the population were to increase to 90,000 people, each using 100 gallons of water a day, we could sustain the yield. At the present rate of use and of evaporation loss, the usable water body will last between 20 and 100 years.

IMPROVING THE SHALLOW AQUIFER

Wells are frequently drilled in and around the playas of desert basins to extract saline water from the central areas. Such wells remove the threat of contamination by saline water to other places in the basin and reduce the evapotranspiration so normal evaporative discharge is captured as useful water. Disposal of the saline water is an obstacle to its removal. Pumping of salty waste water from endoreic basins in Arizona into the Colorado River has caused much acrimony in the past. Fortunately we have a place to put saline water.

Removal of the salty upper water from under China Lake playa is an engineering solution to possible chemical pollution caused by water migration from China Lake playa. This solution requires the construction of a network of ditches a few feet deep to drain the salty water by gravity into Salt Wells Canyon. The water can be carried across the closure into Searles Valley by a ditch or a tunnel 1,000 feet long. The water from China Lake playa can then be impounded or possibly used in Searles Lake.

This solution would lower the shallow aquifer a few feet, remove the saline water, and replace it with good water from the "deep" aquifer. This process would take some years, but the only attention required would be monitoring. Once the upper water is relatively pure, the water table could be dropped so that there would be no evaporation losses from the playa (with a saving of some 8,000 to 10,000 acre-feet per year). The whole water table could then be lowered below the 2,150-foot level to prevent contamination of the main aquifer caused by excessive water level decline elsewhere. This project could extend the useful water supply of the Valley. If this project is undertaken, it should be started before the water table drops more and pumping of the saline water becomes necessary.

INCREASING RECHARGE

In many arid regions of the world, large storms produce runoff from the hills. Holding dams are used to retain this water long enough for it to soak into the ground, rather than allowing the water to run out into the Valley to be evaporated. Occasionally these reservoirs are equipped to inject water into the ground by pumping.

In Indian Wells Valley some surface water runs into the Valley almost every year. Usually the water flows onto the playa, where it evaporates or, worse yet, temporarily raises the level of the saline shallow aquifer. Dams, shown in Figure 21, should be built north of the Terese ground-water barrier in Little Dixie Wash, El Paso Wash, and Ridgecrest Wash to form spreading dams. Land acquisition cost need not be high, because this land is owned and controlled by the Bureau of Land Management.

It is difficult to estimate the amount of water that could be collected by holding dams. It is not uncommon for the infrequent rains on the "headwaters" these of washes to produce 10 to 50 acre-feet per storm. Flows during 100-year floods exceed 1,000 acre-feet per wash. Even if flood-level rains occurred only every few years, it would be beneficial to collect this water. An added advantage would be the provision of some level of flood protection provided by the collection system; the savings in cost of construction for buildings and in flood insurance will easily pay for the facilities in a few years.* Instead of allowing the flood water to naturally flow into the playa, where water would be lost, this system offers the opportunity of effectively using flood water to recharge the ground-water table.

In some water-poor areas, notably tropical islands, inhabitants have removed hillside vegetation and coated the ground with cement, asphalt, or plaster to channel water into sites for transportion, ground injection, or irrigation use. In some desert areas, crops are grown alongside paved roads. Rainwater cannot soak through the surface and, thus, becomes preferentially available to areas adjacent to the road. The benefit of strip growing can be seen in the local area. Creosote bushes are always larger along the road than a few hundred feet away.

DESALINIZATION

Desalinization of brackish water by conventional means is not economically attractive. A limited amount of brackish water is available from areas where pumping is difficult. At present, water purified by distillation or by reverse osmosis costs about $1.00 per thousand gallons. Even at this cost, about 780 such plants were in use around the world in 1970 serving isolated localities, and the aggregate production then was about 250 million gallons per day. In 1985 production will be in excess of 1 billion gallons (or 3,000 acre-feet) per day. The increasing cost of fossil fuel and the lessening availability of land continues to work against the widespread application of this technology.

However, one approach to the problem would be to invert the intent of a solar energy power plant. If a 10-megawatt plant were to be constructed in the Valley near the sewage ponds and the upper aquifer, it would probably be economically feasible to use waste heat to recover water for residential and industrial uses. Such a plant could produce about 2,000 acre-feet per year of distilled water, bring about 3 million dollars in electrical revenue, and save a great deal of fossil fuel. The plant could operate for centuries, using waste water from the upper aquifer and reclaiming sewage water. Removing contaminated water from the basin would eventually improve the overall aquifer without the necessity for draining the upper aquifer into Salt Wells Valley. This solution may prove to be the best way of handling the problem of waste water.

WEATHER MODIFICATION

Rainmaking is a recognized scientific development. The snow pack and annual precipitation can be doubled by using the process correctly. Kern County engages in rainmaking in dry years but not in average or good water years. The opportunities for increasing recharge to Indian Wells Valley are somewhat limited during the normal winter frontal storms that pass through the Valley. Normal winter storms come from the southwest through west quadrant; seeding these storms would yield less water for our watershed

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* If spreading dams had been constructed before the August 1984 flood, flood damage to NWC, Ridgecrest, and Inyokern would have been mitigated.

than for others. However, storms that come through the southwest through southeast quadrant and passing low-pressure areas can be seeded effectively to increase the precipitation in the Argus and Coso Ranges and in the Sierra Nevada.

SUGGESTIONS FOR AUGMENTING VALLEY WATER SUPPLY

Even if we practice water economy, we probably will eventually run out of water. At present we are using water beyond our means. If we were to adopt a different life-style and use water sensibly and economically, within the bounds set by climate, soil, and hydrology, we could postpone the day of hydrologic reckoning almost indefinitely. This is not likely to be the case when one considers the long time necessary to establish facts, negotiate and reach decisions, and the reluctance of the public at large to understand and accept the necessity for change. The complexity of county and state government control over such activities and the difficulty of dealing with the federal bureaucracy in environmental matters does not make arriving at sensible solutions any easier.

Parkinson's Law ("Water-Lemma"): *Water use rises to meet demand; the demands rise to meet the supply.* Short-term economic goals are more attractive to the rate-paying public and to the managers of public systems than the initially more expensive, but eminently more sensible, long-term solutions involving some higher level of capitalization and self-sacrifice. In view of this, some sources for augmenting the water supply of the Valley are presented below.

The use of water can be controlled to some extent by the pricing. While it is wise to keep the cost of necessary amounts of water as low as possible in order to restrain the cost of living and of doing business, it is not necessary to encourage reckless use by flat-fee pricing. Metering of water use and graduated fees would reduce water use greatly. The practice of some water companies of charging flat fees should be discouraged. Change of rate structures is the easy way to accomplish water conservation--although not necessarily the best. Pumping of water by agricultural activities during times of low power consumption because of preferential power rates during those times should be discouraged. For their mutual benefit in implementing and financing aquifer and water-table preservation programs, individual well owners should be assessed a wellhead fee based on the amount of water used.

PUMPING FROM ROSE VALLEY

Water could be pumped from Rose Valley. About 2 million acre-feet of good water are in storage there. The useful life of that aquifer under our present usage would be about 100 years. The recharge to Rose Valley has been estimated, on the basis of evapotranspiration and seepage through the gap at Little Lake, to be about 800 acre-feet per year. Some estimates based on the area and altitude of the catchment basin are much higher. If 1,000 acre-feet of water per year were withdrawn, Rose Valley could be used as a supplemental water supplier for thousands of years. It would be necessary to take legal steps to get the Rose Valley water rights, and this may not be possible. Other uses may prevail. It might be necessary to reserve this water for use in the geothermal power plants envisioned for the Coso Geothermal Field. The agriculture that now exists in Rose Valley is not making a serious demand upon the capacity of that valley.

DRAWING FROM OWENS VALLEY

We might arrange to use surplus water from the Los Angeles aqueduct during years when water is plentiful. In late 1982 and early 1983, the Los Angeles Department of Water and Power (LADWP), having exhausted its storage capability and taxed its delivery systems to the utmost, was forced to release into the dry bed of Owens Lake several times the annual recharge to Indian Wells Valley. Later, this water was released into Rose Valley instead, where it could augment the ground-water supply and possibly be recovered in the future. With proper arrangements, such as a pipeline into Indian Wells Valley or a tap onto the aqueduct, excess water could be delivered to the local system and used directly or stored in the ground for future use. If this arrangement with the LADWP is made, we must have a legally binding contract so that Indian Wells Valley cannot be added to the LADWP reservoir capacity and be subjected to later water withdrawals. Buying the surplus water outright at a reasonable fee is the most acceptable alternative.

To expect that water could, or would, be perennially available from the Los Angeles aqueduct is not reasonable because the needs of that city are so great that the water supply is scant during all but the wettest years.

About 85,000 acre-feet per year additional water, not now being used, could be recovered from the area around Owens Lake and transported either by the existing aqueduct to Indian Wells Valley or by a pipeline built for the purpose. Some of this water is currently being used by alfalfa farmers near Cartago.

CAPTURING FROM SIERRA NEVADA

Chimney Creek

Chimney Creek is fed by a catchment area lying just to the east of the head of Nine Mile Canyon. About 5,000 acre-feet per year could be captured, without pumping, if a tunnel about 1,200 feet long were drilled between Chimney Meadow and Nine Mile Canyon. This small amount of water could run into Nine Mile Canyon and from there recharge the ground-water table in Indian Wells Valley. It would also be feasible to carry it in a pipeline to the north end of the line of wells that I propose. If this were done, some electrical power could be generated by a water turbine plant built at the bottom of Nine Mile Canyon. This electricity could be used to power the pump line in the Valley or could be sold commercially. This scheme, Route 1 on Figure 21, is the cheapest source of additional water and would be of considerable help.

Chimney Creek could also be captured at Lamont Meadow. Two choices exist: if water is captured at the northern end of the meadow, the water could be carried by a 3-mile pipeline to the 6,000-foot level, passed through a 0.5-mile tunnel, and released into Sand Canyon. If captured from the lower end of Lamont Meadow, the water could be picked up at 5,520 feet, taken by pipe for 3 miles to the 5,600-foot level and through a 0.6-mile tunnel to the South Fork of Sand Canyon. If the total output of Chimney Creek were captured at Lamont Meadow, about 10,000 acre-feet per year could be obtained. No stream gauging has been done on this creek, and the estimates are based on altitude, area, and rainfall; hence, the quantity is uncertain, but there is clearly enough water to make development worthwhile. The water could be released into the canyons or brought down in a pipeline and used to generate power. Routes II and III, although very practical and water productive, are more expensive than Route I (See Figure 21).

South Fork of the Kern

The South Fork of the Kern is a south-flowing stream that delivers 80,000 acre-feet a year, on the average, to Lake Isabella. In most years, this water is held in the Lake for use in Bakersfield the next summer. In wet years, however, too much water is available and it stretches the ability of the system at Isabella to handle it. If the unneeded water could be diverted into Indian Wells Valley during flood years everyone would benefit. During periods of high water, the excess is dumped into Kern Lake, where it evaporates.

Route IV would pick up the water at mile 44.5 on the River, at 5,820 feet, carry it by a 13-mile pipeline passing a maximum elevation of 7,850 feet, and reach the head of Nine Mile Canyon at 6,000 feet. Route V would pick up the water at mile 39.5 on the River, at an elevation of 5,560 feet, and bring it via a 9-mile pipeline along the Rockhouse Basin Road over a maximum elevation of 7,850 feet to the head of Nine Mile Canyon.

From the head of Nine Mile Canyon, the water could be carried by pipeline to the main collector line on the string of wells proposed elsewhere in this paper. En route, the water could probably generate enough power to pay for the pumping. The net difference between the elevation of the pickup points and the powerhouse is in excess of 2,500 feet for all these schemes.

INTERCEPTING FROM CRUSHED-ROCK ZONES IN SIERRAN BEDROCK

Dr. Carl Austin repeatedly has called attention to the possibility of intercepting water in large crushed-rock zones in the Sierra. This situation might be exploited if a gallery were driven into the Sierra at about the 5,600-foot level in Nine Mile Canyon straight west beneath the southern end of Chimney Meadow. The entire fault zone could be crossed with a 0.7-mile tunnel that would tap water stored in the fault zone as well as that collected from the surface. Similarly, such a gallery could intercept water from Lamont Meadow. A 5-mile tunnel from Little Lake Canyon or Five Mile Canyon under Sacatar Meadow could yield 20,000 or more acre-feet per year, if the crushed zone in the fault is permeable and large enough.

Exploratory drilling must precede any decision to construct galleries. Such drilling would determine not only whether the crushed zones would yield sufficient water but also which are the best sites to reach with galleries. Tunnels that have inadvertently penetrated such fault zones elsewhere have yielded quantities of water and have caused no end of inconvenience. This method of obtaining water has been used in the Middle East. Ghanats, tunnels tens of miles long, were cut into the water table in poorly porous sandstone. The city of Honolulu uses a large gallery for a water supply. A variant of this technique gives Indian Wells Valley its name.

The idea of tunneling into large crushed zones is practical because water is trapped beneath an area of relatively high rainfall. Water collected in the rock would provide a buffer during drought years. Tunneling presents no serious engineering problems, the land surface would not be defaced, and the water withdrawn would scarcely be noticed, although some authority for appropriating the water would be needed. If prospect wells revealed sufficient water, a gallery system would be more practical than capturing surface water with intakes and pipelines.

The water obtained from any of these schemes would be available at reduced pumping cost and distributed directly to Ridgecrest, China Lake, Inyokern, and Trona. When excess water is available, at night and in the winter, the water could be injected into the pumping

depressions at Inyokern, at the Intermediate and Ridgecrest pumping fields. Judicious use of water from these sources could give a steady-state solution to our water problems.

RECOMMENDATIONS FOR IMPROVING VALLEY WATER SUPPLY

In the following discussion, each recommendation makes a contribution to improving the Indian Wells Valley water budget. It is not possible to say exactly how much water can be obtained with the information currently at hand, nor how much each step of the proposed projects will cost. The various suggestions, including projected costs and benefits, are listed in Table 9, together with an estimate of the benefits and the expenses involved.

Improving the water supply requires planning—establishing which measures to take and establishing what order in which to take them. The success and the expense of each succeeding step will depend upon the order in which the preceding steps were taken. Some of the measures are just good housekeeping. Some measures are necessary to demonstrate that optimal use is being made of water, and that more water is needed; these measures establish the political and legal basis for proceeding to procure water from outside the Valley. Many of the measures can be taken concurrently. Suggested measures for improving the Valley water supply are as follows:

1. Establish a Valley-wide water agency
2. Institute a campaign for public awareness of the need for water economy, for developing more water, and for paying for it
3. Determine the water budget more accurately
   a. Reestimate the recharge and discharge
   b. Determine the quantity and quality of water available from the north and east sides of the Valley
   c. Determine the flow of Chimney Creek
   d. Prospect Sacatar Canyon and Chimney Creek fault zones for water
4. Establish the optimum use of existing water systems
   a. Dispose of sewage water constructively
   b. Remove the water from the saline aquifer on China Lake
   c. Convert alfalfa production to some less water-intensive crop
   d. Use household "gray water" for domestic irrigation
   e. Encourage "desert landscaping"
   f. Encourage new housing designs to minimize water use
   g. Employ cloud seeding in the area
5. Construct spreading basins in Little Dixie, El Paso, and Ridgecrest Washes
6. Install, if economically sound, a Coso-Argus collector system
7. Install the west side well line from Inyokern Road to foot the of Nine Mile Canyon
8. Tunnel into the fault zone beneath Chimney Peak, if water is adequate
9. Capture water from Chimney Meadow and divert it into Nine Mile Canyon
10. Construct a pipeline from the north end of the west side well line to the head of Nine Mile Canyon
11. Construct a pipeline from the South Fork of the Kern River to the head of Nine Mile Canyon
12. Divert South Fork and Chimney Creek water into the Nine Mile Canyon pipeline
13. Construct a power plant near the mouth of Nine Mile Canyon to produce power from the water
14. Take steps that may be desirable later, e.g., arrange for surplus water from Rose Valley and Owens Lake, and tap water stored in fault zones in the Sierra

TABLE 9. Comparison of Available Options for Increasing Usable Water Supply.

Item	Reason for doing	Tech-nical diffi-culty	Political diffi-culty	Practi-cality	Water gain, acre-ft/yr	Capital costs	Remarks
Water Economy	Save water						
Sewage recovery	Prevent leak-age	Low	Some	High	2,000	?	Depending on use costs
Desert landscaping	Prevent evap-oration	Low	Some	High	2,000 +	Low	
Agricultural changes	Prevent evap-oration	Low	High	High	8,000 +	100,000	Potential economic gains
Passive architecture	Prevent evap-oration	Low	Some	High	1,000 +		High potential for comfort
Spreading basins	Collect runoff	Low	Low	High	Variable	500,000	Flood control advantage
West side line	Collect water lost to dis-charge	Low	Low	High	7,000	3-4,000,000	Also serves to collect imported Sierra water
Water Budget Reassess							
IWV budget	Find out how much water is available	Low	None	High		50,000/yr	Study would take 3 years
Gauge Chimney Creek	Find out how much water is available	Low	None	High		10,000	
Prospect Sacatar and Chim-ney Cr fault zones	Find out how much water is available	Low	None	High		100,000	Drill wells in zone
Collect Extra Water							
Argus-Coso line	Collect water now lost	Low	Some	High	2-3,00	5,000,000	Depends on quantity and quality
Tunnel to fault zone	Collect stored water	Low	High	High	5-20,000	500,000	Depends on quantity and quality, exploratory results
Chimney Creek	Collect surface water	Low	High	High	5,000 ±	500,000	Tunnel driving into Nine Mile Canyon
South Fork Kern	Collect surface water	Low	Some	High	20,000 ±	2,500,000	Pipe to head of Nine Mile Canyon
Rose Valley	Collect ground water	Low	High	High	1,000	1,500,000	Pumping only low yield
Owens Valley	Collect ground water, around Owens Lake	High	High	Low	40,000 +	?	Feasible in wet years
Buy from LADWP	Get water from L A aqueduct	Low	High	Low			Feasible in very wet years
Improving Aquifer							
Drain upper aquifer	Drain to Salt Wells	Mod	Low	High		500,000	Prevent pollution
Small solar power plant	Distill water with waste heat	Low	Low	High	2,000 +	10,000,000	Would net $3,000,000 in electricity per year
Other facilities							
Nine Mile pipe	Collect water from Sierra	Low	Low	High	Up to 30,000	2,000,000	Puts water into distri-bution system
Nine Mile power plant	Generate energy for pumping	Low	Low	High		10,000,000	Will generate extra power

WATER MANAGEMENT STRUCTURE

If we assume that the NWC is essential to the security of the United States and that the Kerr-McGee operation in Trona is essential to the economy, as indeed they are, then the question of keeping the Valley water supply in production as long as possible becomes a very important consideration. Things were simpler a few years ago when the Navy virtually owned and controlled the Valley. Recent administrative decisions to shift the populace from NWC to other parts of the Valley and to rely heavily on contractors to do a large part of the increasing work load of the Center have distributed the authority and the responsibility. A rather large, external group of people and agencies is now involved in the decision-making process. While the Navy clearly has some prior preemptive rights in the matter, as does Kerr-McGee, it is not possible that management by fiat can be carried out. It is also obvious that the successful functioning of the Valley as a whole is necessary to the continued success of the Navy and of Kerr-McGee and is even more clearly in the national interest. Politically, decisions about the Valley water supply cannot be left in any one group's hands. NWC has shown admirable foresight in agreeing to cooperate in the siting of new wells. In order to carry out the systematic conservation, efficient use, and equal distribution of the water we have, and to arrange acquisition of new water, some legal arrangement must be made to manage the Valley as a whole.

The primary water users in Indian Wells Valley are alfalfa growers, Indian Wells Valley Water District, NWC, Kerr-McGee Corporation, Sierra Pacific Lumber, Antelope Valley Water Company, Ridgecrest Heights Water Company, and several hundred operators of individual wells. These entities are autonomous and have similar but not identical goals and viewpoints. All use water from a common source and all are affected, sometimes gravely, by actions of others. Operating separately, none can be effective in arranging an optimal system for the whole of the Valley in instituting important economies, or in developing additional water. Moreover, no one system can compel any or all of these entities at any reasonable cost to purchase water from any one purveyor. Disputes are settled by the adversary process, and this rarely leads to equitable or economic solutions to serious problems.

A step in the right direction was the formation of a committee by the local major water users to look into methods to determine the amount of water available and to consider effective methods of pumping and pooling resources. We should go one step farther and set up arrangements for a Valley-wide water management agency consisting of the various water users and the public at large. A Valley-wide water agency that would respect and defend the rights and needs of individual users and that could obtain an approach to water production should be set up immediately.

Once established, the agency could speak for the Valley, institute economies of use, obtain water from other sources, arrange for construction of the west side well line and the Argus-Coso collector system, install spreading basins, and so on. Long-term loans could be obtained to bring about these improvements. Improvements to individual systems would, of course, be the responsibility of the individual property owners and operators. The loans and operating expenses could be paid for by use charges assessed on all water users within the Valley, in proportion to the amount of water used.

Until such an agency is established, little or no progress can be made in ensuring a steady-state water supply to the Valley. Once such an agency is functioning, progress can be rapid. If such an agency is not formed soon, it is very likely that either the State or Federal Government will take it upon itself to do so. This action will remove any possibility of control from local hands and will effectively prevent a satisfactory system from ever being developed.

CAVEAT

The State of California uses twice as much water as it receives on a yearly basis. The demand is continually rising. Dumping of water into the Sacramento Delta to decrease salinity results in a serious loss of useable domestic and irrigation water, a loss that could be avoided by construction of dikes and locks i.1 Carquinez Straits. In order to pass the bill permitting construction of the Peripheral Canal, it was necessary to reject use of water from the coastal ranges in the San Joaquin Valley; thus, considerable water that is vitally needed in the Central Valley is returning to the ocean from the northern coast range rivers. Water is carelessly wasted statewide, except in times of drought, when those measures normally regarded as prudent are adopted as if they were hardships. Recent Supreme Court decisions have deprived the Los Angeles Metropoltan Water District of a major portion of the water it now receives from the Colorado River. California's population is still increasing and more land is being put into cultivation than can be permanently supplied with water. By the time the inhabitants of Indian Wells Valley get around to acquiring water from outside the Valley, it may already have been appropriated by another agency, such as the city of Los Angeles or some other burgeoning urban area.

Any attempt to obtain permission to import water will require that we demonstrate that we have practiced water conservation as much as possible and have done all those things necessary to optimize the water procurement and distribution systems within Indian Wells Valley. Almost all of the water in the Sierra has been allotted to some other agency. Negotiations will be necessary to purchase water or to obtain an allotment from the state before any can be collected. New legislation might have to be passed by the State Legislature. Such negotiations take time, and the time required for decision making and negotiation is becoming progressively longer with each passing year.

In short, we must begin to act soon and act with some dispatch. We must organize a Valley-wide water district, develop our indigenous resources, and clearly demonstrate that we are doing the best we can to get by on what we have. Sensible economy of water use, intelligent planning and development, and mutual cooperation are the only pathways open to us that will lead eventually to a more stable, steady-state system and to the protracted use and enjoyment of Indian Wells Valley.

ANNOTATED BIBLIOGRAPHY

Appel, Charles A., and John D. Bredehoeft. "Status of Ground-Water Modeling in the U. S Geological Survey," USGS Circular 737, 1976. 9 pp.
    Short discussion of the state of mathematical modeling of ground-water systems. Includes an excellent bibliography.

Baldwin, Helene L., and C. L. McGuiness. "A Primer on Ground Water," USGS, Washington, D.C., GPO, 1963. 16 pp.
    Brief, clear discussion of the principles of ground-water occurrence and exploitation methods. Recommended for beginning study.

Banta, R. L. "Ground-Water Data for Indian Wells Valley, 1972," USGS Open File Report, June 22, 1972. 10 pp.
    Contains water levels, hydrographs, and chemistry of Indian Wells Valley.

Bear, Jacob. *Dynamics of Fluids in a Porous Media.* New York, American Elsevier Publication Co., 1972.
    Modern text on fluid flow. Contains more than one really needs to know.

Blaney, Harry F. "Determining Evapotranspiration by Phreatophytes from Climatological Data," *Transactions of the American Geophysical Union*, Vol. 33, No. 1 (1955), pp. 61-66.
    Contains a detailed discussion of the methods to determine water use as well as of the application of these data to determine the water use on the basis of phreatophytes and climate.

_____. "Evaporation From and Stabilization of Salton Sea Water Surfaces," *Transactions of the American Geophysical Union*, Vol. 36, No. 4 (1955), pp. 633-640.
    A study of evaporation as applied to a slightly saline water body. Applicable to other desert lakes containing saline materials.

_____. "Evaporation Study at Silver Lake in the Mojave Desert, California," *Transactions of the American Geophysical Union*, Vol. 38, No. 2 (1953), pp. 209-215.
    Silver Lake is a dry playa in the eastern Mojave Desert that is occasionally flooded by runoff. Evaporation rates for surface water on this lake are applicable to other desert lakes in the same region.

Blaney, H. F. and W. D. Criddle. "Determining Water Requirements in Irrigated Areas From Climatological and Irrigation Data." U. S. Department of Agriculture, Soil Conservation Service, Technical Paper 96. 48 pp.
    This paper tells how to determine how much water is being used for irrigation on the basis of acreage, drop type, watering methods, and climatology.

Blaney, Harry, and Dean C. Muckel. "Evaporation from Water Surfaces in California," Bulletin No. 73, State of California, Dept. of Water Resources, Oct. 1959. 81 pp.
    Standard reference on evaporation compiled from published sources. Contains 17 tables and four figures.

Bloyd, R. M., and S. G. Robson. "Mathematical Ground-Water Model of Indian Wells Valley, California," USGS Open File Report, Water Resources Division, Menlo Park, Calif. Nov. 12, 1971.

Two-dimensional computer model of the water table in Indian Wells Valley. The authors used the work of Kunkle and Chase and the conceptual model of Dutcher and Moyle.

Cloudsley-Thompson, J. L. *Man and the Biology of Arid Zones.* London, University Park Press. 182 pp.
Helps to understand local problems in a wider framework. Excellent background material for anyone interested in deserts, water use, physiology, and biology of arid regions.

Cox, Brett Forrest. *Sedimentology and Structure of the Goler Formation (Paleocene) El Paso Mountains, California: Implications for Paleocene Tectonism on the Garlock Fault Zone.* Unpublished Ph.D. dissertation, University of California, Riverside, March 1982.
A detailed study of the sedimentation, tectonics, and geologic history of the Goler and Ricardo formations. This document gives more information than any previously compiled document and contains dates and types of geologic activities.

Davis, Stanley N., and Roger L. M. de Weist. *Hydrogeology.* New York, John Wiley & Sons, 1966.
Good, modern text on ground-water geology, mixed with some hydrology. Well written, easy to understand, and thorough. Companion piece to de Weist's *Geohydrology.*

Dibblee, Thomas W. "Aerial Geology of the Western Mojave Desert, California," in *Contributions to West Coast Earthquake Investigation,* USGS Professional Paper 522, 1967.
An excellent summary of long and arduous field geology. It explains the origin, timing, and nature of the Goler and Ricardo Formations as well as the materials underlying most of Indian Wells Valley.

Duffield, Wendell A., and George I. Smith. "Pleistocene History of Volcanism and the Owens River Near Little Lake, California," *Journal of Research,* USGS, Vol. 6, No. 3 (May-June 1978), pp 305-408.
Very good discussion of Pleistocene Lakes and chronology of lava flows. This paper is about the geomorphology and volcanism of the region near Little Lake.

Dutcher, L. C., and W. R. Moyle, Jr. "Geologic and Hydrologic Features of Indian Wells Valley, California," USGS, Water Supply Paper 2007, Washington, D.C., GPO, 1973. 30 pp.
Compact review of the known geology and hydrology of Indian Wells Valley in the late 1960s. The authors used Kunkle and Chase's work, added information from Zbur's research (which Moyle participated in), and included data from other sources. The conceptual model on which the computer model of the ground water is based is presented. This document is compact and clearly written. It contains so much data that it needs to be read very carefully. Five maps give reliable, detailed information about many physical features of Indian Wells Valley, including a three-dimensional diagram based on the work of Zbur.

Gale, Hoyt S. "Salines in the Owens, Searles, and Panamint Basins, Southeastern California," USGS Bulletin 580-L, 1913.
Description of the ancient lakes along the Sierra Nevada as well as the minerology of the concentrated saline material. Gale made the first and most important studies of the occurrences of now dry lakes in this region—a classic paper.

Goudie, Andrew, and John Wilkinson. *The Warm Desert Environment.* Cambridge, University Press, 1977, 88 pp.

    Compact and useful discussion of warm deserts, desert processes, land forms, water occurrences, hydrology, and hydrologic factors in desert development. Numerous photos and figures.

Healy, J. H. and Frank Press. "Geophysical Studies of Basin and Range Structures Along the Eastern Front of the Sierra Nevada, California," *Geophysics*, Vol. XXIX, June 1964, pp. 337-359.

    This work, an ancillary study to Zbur's research, discusses the depth of fill and internal structure of the materials beneath Indian Wells Valley's floor. Studies of the structure of valleys in the Great Basin and Transitional regions give data based on seismology and gravitational studies for Indian Wells Valley and the area to the north.

Koehler, J. H. "Ground-Water Conditions During 1970 in Indian Wells Valley, California," USGS Open File Report 7211-25, Menlo Park, Calif. November 26, 1971. 19 pp.

    Discussion of 1970 conditions. Contains data on Navy and Indian Wells Water District wells. Includes figures and tables.

Kunkle, Fred, and G. F. Chase. "Geology and Ground Water in Indian Wells Valley, California," USGS Open File Report, Water Resources Division, Menlo Park, Calif., January 23, 1969. 84 pp.

    Masterpiece of clear writing and excellent insight into the area's geology and hydrology. Although this paper was published in 1969, it was first circulated in 1952. It was largely from this report, supplemented by work of their own, that the text of Dutcher and Moyle was prepared and released in 1973. Their study furnished the hydrologic basis of the computer model prepared by Bloyd and Robson.

Lamb, Charles E., and D. J. Downing. "Ground-Water Data, 1974-1976, Indian Wells Valley, Kern, Inyo and San Bernardino Counties, California," USGS Open File Report 78-335.

    Valuable reference. Gives data on water levels in about 95 wells in Indian Wells Valley. Includes hydrographs, shows changes by month and year, chemical composition of the water, and so on. Includes illustrations.

————. *Ground-Water Resources of Indian Wells Valley, California.* California State Conservation Committee Report, 1913.

    First definitive study of ground-water conditions in Indian Wells Valley. This hard-to-find report gives the estimate for the Valley's water inflow as well as the evaporative discharge. Also gives land and water use data for 1913.

Lee, C. H. "An Intensive Study of the Water Resources of a Part of Owens Valley, California," USGS Survey Water Supply Paper 429, 1913. Pp. 53-60.

    Discusses the water budget of Owens Valley and Indian Wells Valley and gives Lee's method of determining the water budget of desert basins. This paper is a classic and should be read by everyone interested in desert ground water. Unfortunately, the paper is out of print.

Lee, W. T. "Geology and Water Resources of Owens Valley, California," USGS Water Supply Paper 181, 1906.

    The first comprehensive study of the water resources of the Owens Valley. Contains comments about the rainfall, history, and water usage.

Leopold, Luna, and Walter B. Langbein. *A Primer on Water* USGS, Washington, D.C.
GPO, 1960.
Excellent, simple discussion of water. Covers some of the same discussion as
Baldwin and McGuiness.

Lipinski, Paul, and Darwin Knochenmus. "A Ten-Year Plan to Study the Aquifer System of
Indian Wells Valley, California," USGS Open File Report 81-404, June 1981. 16 pp.
Presents an elaborate plan to learn more about the details of Indian Wells
Valley's aquifer system. This plan involves (1) drilling additional observation and
test wells, and (2) a more careful study of the provenance and quality of the Valley's
water.

Lohman, S. W. "Ground-Water Hydraulics," Geological Survey Professional Paper 708,
1979, 70 pp.
Useful and reliable, although the writing is compact and precise. Text is the
course content the author developed for use in Australia. This is a good book for
someone who wants to work in the field.

Mallory, Michael J. "Water Level Predictions for Indian Wells Valley Ground-Water Basin,
California, 1978," USGS Open File Report 79-254, Menlo Park, Calif., 1978. 28 pp.
Good discussion. This report presents ground-water depth conclusions based on
the performance of the computer model as well as predictions about contamination to
the water supply from the China Lake playa. Results obtained from the model are
more conservative than actuality because of differences in estimated and actual
water use.

Moyle, W. R., Jr. "Data on Water Wells in Indian Wells Valley Area, Inyo, Kern, and San
Bernardino Counties, California," Bulletin No. 91-9, State of California,
Department of Water Resources, 1963. 243 pp.
Valuable to anyone interested in the water problems of Indian Wells Valley.
This bulletin describes the Valley geology and hydrology. It was compiled during
several years of Moyle's investigations of the area's wells. He collected records and
logged every well in the area he could find. References, plates, and a large map are
included.

Meinzer, Oscar Edward. "The Occurrence of Ground Water in the United States With a
Discussion of Principles," USGS Water Supply Paper 489, Washington, GPO, 1965.
321 pp.
Excellent text for anyone wanting a general knowledge of ground water. Many
examples are taken from Owens Valley and deserts throughout the world. Initially
published in 1923, it has not been much improved upon. Includes plates and figures.

Rantz, S. E. "Mean Annual Precipitation in the California Region," map published by the
Geological Survey, Edition of 1940, Menlo Park, Calif. 1967.
Large map showing the rainfall in California.

Rockwell, Inc. "Preliminary Draft of the Coso Hydrologic Report," (EMSC8321.17HTR).
Excellent investigation and report on the Coso ground water.

Smith, G. I. "Origin of Lithium and Other Components in the Searles Lake Evaporites, California," in *Lithium Resources and Requirements by the Year 2000*, ed. J. D. Vine. USGS Professional Paper 1005, 1976.

> Gives details about the filling and drying of desert lakes and corresponding changes in the climate. Contains the premise that Owens Lake drainage into Rose Valley stopped about 2,000 BP based on the amount of evaporites now in Owens Lake.

Smith, G. I., and F. Alayne Street-Perrott. "Pluvial Lakes in the Western United States," in *Late Quaternary Environments of the United States*, H. E. Wright (ed.) of the series *The Late Pleistocene*, ed. Stephen C. Porter. University of Minnesota, 1983.

> An excellent analysis of past climates based upon the history of the desert lake chain that formerly existed in this area. This paper will eventually be regarded as a classic in the field.

Smith, G. I., and Walden P. Pratt. "Core Logs from Owens, China, Searles, and Panamint Basins, California," USGS Survey Bulletin 1045A, 1957. 62 pp.

> A well core from Owens Lake is described in detail. This core shows that the lake was full of water almost constantly from during the Tahoe-Tioga interstage.

Thompson, D. G. "The Mojave Desert Region, California," USGS Water Supply Paper 578, 1929.

> An early summary of the ground-water potential for the Mojave Desert region. Contains information on Indian Wells Valley, Rose Valley, Salt Wells Valley, and Poison Canyon. Also shows that there were 108 wells in 1929 in Indian Wells Valley.

_____. "Routes to Desert Watering Places in the Mojave Desert Region, California," USGS Water Supply Paper 490, 1921. Pp. 87-269.

> The whereto and howto of finding water in the Mojave Desert and other deserts. Interesting short discussion of how to get from Mojave to Little Lake in the early 1900s, showing the very few places that water was available.

U. S. Naval Ordnance Test Station. *A Geophysical Investigation of Indian Wells Valley, California*, by Richard T. Zbur. China Lake, Calif., NOTS, July 1963. 98 pp.

> Sound background for understanding the area and for future work. Discusses general geology, shows seismic profiles for Indian Wells Valley, and includes analysis of magnetic and gravitational surveys. Contains 64 references that deal with the immediate area, as well as plates and figures.

_____. *Geological Investigation of Airport Lake as a Clay Target Site*, by Roland Ernst von Huene. China Lake, Calif., NOTS, 1955. 50 pp. (Technical Progress Report 132, publication UNCLASSIFIED.)

> Describes the physical properties of Airport Lake for use as a target. The report discusses the mechanism of sedimentation in desert basins, and the sediments encountered drilling a number of holes in the dry lake bed to determine the sedimentary and stratigraphic structure.

von Huene, Roland Ernst. "Structural Geology and Gravimetry of Indian Wells Valley, Southeastern California." Doctoral thesis, University of California at Los Angeles, 1960. 78 pp.

> Gives gravimetric maps and an excellent presentation of the geologic structure of the area in and around Indian Wells Valley. Von Huene began the study while he was stationed at NOTS as a sailor; he completed it after his discharge.

Warner, James W. "Ground-Water Quality in Indian Wells Valley, California," USGS,
Water Resources Investigation 8-75, Menlo Park, Calif., 1975. 59 pp.

Excellent summary of the chemistry of individual wells in the valley. The
question of increasing salinity with the depth of the well is clearly discussed.
Warner's viewpoint is somewhat different from that of the other authors because his
concern is primarily chemical. His work supplements the early work of Kunkle and
Chase and of Dutcher and Moyle.

SUPPLEMENTAL BIBLIOGRAPHY

The Supplemental Bibliography contains references pertaining only to Indian Wells
Valley and its hydrology. These supplemental references complement the extensive
Annotated Bibliography.

This Bibliography emphasizes the amount of research that has focused on the water
supply of Indian Wells Valley. In fact, the published research is so extensive that the sheer
volume of words numbers close to 750,000.

Hydrologic research in this area began shortly after the turn of the century. C. H. Lee
published a definitive study in 1913 on the hydrology of Owens and Indian Wells Valleys.
This hydrology study also includes a method of determining the amount of water that flows
into desert basins and the rate of its evaporation and transpiration. This research, conducted
from horseback and on foot, is probably the most accurate and thorough of all the studies in
the past 70 years.

The bulk of studies concerned with Indian Wells Valley were researched and published
from the mid-1950s through the late 1960s. Most of these water studies were done by
Kunkle, Chase, Moyle, and Pistrang of the USGS for the Navy during the expansion of its
RDT&E facility at China Lake. Bloyd and Robson developed the mathematical model of
ground-water movement during this period based on the geologic work of von Huene, the
geophysical studies of Zbur, and the hydrologic studies of the USGS geologists.

The number of comprehensive hydrology studies, including this one, done in and around
Indian Wells Valley should lay to rest the controversy surrounding the amount of available
water for consumptive use.

Bailey, Paul. "Report on the Water Supply of Indian Wells Valley, Kern County, California
to the Lands Division, Department of Justice," 1946.

Banta, R. L. "Ground Water Conditions During 1971 in Indian Wells Valley, California,"
USGS Open File Report, Menlo Park, Calif., 1972.

Giessner, F. W. "Ground-Water Conditions During 1964 at the Naval Ordnance Test Station
and Vicinity, China Lake, California," USGS Administrative Report, 1965.

Isely, M. D. Flood Control and Water Conservation In Indian Wells and Searles Valley.
(Unpublished manuscript.) 1971.

Kunkle, Fred. "Ground-Water Conditions During 1954-1955 at the Inyokern Naval
Ordnance Test Station and Vicinity, California," USGS Administrative Report,
1955.

Kunkle, Fred, and G. H. Chase. "Geology and Ground Water of the Inyokern Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1955.

Kunkle, Fred, G. H. Chase, and W. J. Hiltgen. "Tables of Selected Data to Accompany U. S. Geological Survey Report on Geology and Ground Water of the Inyokern Naval Ordnance Test Station and Vicinity," USGS Open File Report, Menlo Park, Calif., 1954.

Kunkle, Fred, and M. A. Pistrang. "Ground-Water Conditions During 1955-56 at the Inyokern Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1957.

Kunkle, Fred, and G. F. Worts. "Progress Memorandum on the Ground-Water Investigation and Suggested Test-Well Drilling Program for the Inyokern Naval Ordnance Test Station, California," USGS Administrative Report, 1953.

Lipinski, Paul, and Darwin D. Knochenmus. "A 10-Year Plan to Study the Aquifer System of Indian Wells Valley, California," USGS Open File Report 81-404, Menlo Park, Calif., 1981.

Moyle, W. R., and Fred Kunkle. "Ground-Water Conditions During 1959 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1960.

Moyle, W. R., Jr. "Ground-Water Conditions During 1960 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1961.

_____. "Ground-Water Conditions During 1961 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1962.

_____. "Ground-Water Conditions During 1962 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1963.

_____. "Ground-Water Conditions During 1963 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, 1964.

Pistrang, M. A. "Ground-Water Conditions During 1957 at the Inyokern Naval Ordnance Test Station and Vicinity, California," USGS Administrative Report, 1958.

Pistrang, M. A., and Fred Kunkle. "Ground-Water Conditions During 1958 at the Inyokern Naval Ordnance Test Station and Vicinity, California," USGS Administrative Report, Menlo Park, Calif., 1959.

Westphal, J. A. "Ground-Water Conditions During 1965 at the Naval Ordnance Test Station and Vicinity, China Lake, California," USGS Administrative Report, Menlo Park, Calif., 1966.

Whistler, J. T. "Report on Indian Wells Valley and Fremont Valley, California," California Division of Water Rights Report, 1923.

Wilcox, L. V., J. T. Hatcher, and G. Y. Blair. "Quality of Water in Indian Wells Valley, California." U. S. Department of Agriculture, Salinity Laboratory Research Report No. 54, 1951.

GLOSSARY

Acre-foot - A quantity of water, 1 acre covered by water 1-foot deep.

Agate - Semiprecious stone consisting of microcrystalline quartz. It is hard, translucent, and has a waxy luster. The color may range through the entire spectrum.

Alluvial fan - A mass of sediment emplaced at the mouth of a canyon, spreading out like a fan. Sometimes called a bajada, it is composed of fanglomerate and is usually built by mud flows or debris flows.

Alluvium - Rock debris deposited by the action of water by streams, sheet flood, debris flows, etc. Decayed rock in place is called colluvium. After it has been moved, it is alluvium. If decayed rock is deposited by a stream, it is called fluviatile; by a lake, lacustrine; and by wind, aeolian.

Aquifer - A body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs.

Bajada - A slope leading down from a mountain front. It may be a well-developed alluvial fan of a pediment (a broad, gently sloping erosion surface or plain of low relief, typically developed by running water, in an arid or semiarid region at the base of an abrupt and receding mountain).

Basalt - Hard dark rock rich in iron and magnesium usually found in lava flows. A local example is the deposits along the east side of the road near Little Lake and on Black Mountain.

Bedrock - Also called crystalline basement or basement in solid rocks.

Catchment area - Region over which water is accumulated and fed to a particular site, for example a valley. This area runs to the tops of the surrounding hills or mountains.

Clay plug - Volume of clay buried beneath the central part of a valley floor.

Clastic - Pertaining to a rock or sediment composed principally of broken fragments derived from pre-existing rocks or minerals and transported some distance from their places of origin; also said of the texture of such a rock.

Closed basin - A district draining to a depression or lake within its area from which water escapes only by evaporation.

Closure - Topographic base is surrounded by higher land. In Indian Wells Valley for example, the floor of the China Lake playa is 40 feet lower than the old overflow. This means that the closure of the Valley is 40 feet.

Confining - Layer of rock, soil, or other sediment or material that can impede the flow of water through it. A confining medium prevents water from successfully "seeking its own level," although some flowage will take place. In hydrology confining is used in the horizontal sense and the impediment in the vertical flow.

Consumptive use - Any use of water that is permanently lost from the ground-water basin. The sum of all such uses.

Confining clays or beds - Any type of deposit that impedes the free flow of ground water. Confining clays in Indian Wells Valley are situated over portions of the Valley in such a way as to prevent the vertical movement of water. The confining clays or beds were deposited during a long, still-stand of the ancestral Lake China.

Continental beds - Sediments deposited on land, in a basin, or other depression, as contrasted with marine sediments deposited in an ocean or sea. Lacustrine sediments are a special case of continental deposits.

Debris flow - Heavy rains in desert areas often cause masses of water, mud, rock, sand, gravel, etc. to move rapidly down canyon washes. Debris flows are also called mud flows. These rains, particularly after protracted dry spells, wash out the debris accumulated in the canyons.

Desiccation - A complete or nearly complete drying out or drying-up, such as may result in the formation of evaporates from bodies of water in an arid region.

Detritus - Fragmental material, such as sand, silt, or mud, derived from older rocks by disintegration.

Dissolved solids, dissolved salts - Chemicals dissolved in water, usually expressed in parts per million (ppm). Dependent upon the chemistry, good water usually contains less than 300 ppm dissolved solids.

Drawdown - The lowering of the water level in a well as a result of withdrawal.

Endoreic basin - Internally drained basin or bolson.

Evapotranspiration - Water loss from transpiration by plants combined with evaporation from freestanding water or other sources.

Fanglomerate - Rocks, gravels, and sand deposited in alluvial fan by mud flows or streams. These deposits do not transmit water easily and have a low storage coefficient.

Gallery - Tunnels dug into rock or dirt to collect water, used extensively throughout the world. Water was obtained by a gallery in the late 1800s at the present site of Indian Wells Valley Lodge.

Granite - Grayish-colored igneous rock containing easily visible crystals of feldspar, micas, and quartz. This rock composes the exposed Sierra Nevada.

Granodiorite - Grayish igneous rock that contains the same minerals as granite but with less quartz. This rock is the major constituent of the Sierra Nevada and the bedrock of Indian Wells Valley.

Halophytes - Plants that tolerate salt and alkali well. Although halophytes do not necessarily prefer these conditions, they can persist where others cannot and are hence freed from competition. Salt grass and pickleweed are typically halophytic.

High stand - Highest level reached by a body of water during a particular period.

Igneous rocks - "Fireformed" rocks, derived from melted material within the mantle of the earth, or produced as an extreme product of metamorphism by the melting and recrystallization of sediments or volcanic rocks or other rocks. The local mountains are composed mainly of igneous rock.

Lacustrine -This word pertains to lakes. Sediments deposited in lakes are called lacustrine. They may range from gravels through silts to clays. In the desert, most clays are of lacustrine origin. Also refers to decayed rock deposited by a lake.

Mud flow - A mixture of rock, sand, etc. and water that flows or flowed down a slope.

Molality -A chemical term that has to do with the concentration of dissolved solids in a liquid. The higher the molality, the less easy it is for the solute to evaporate.

Pellicular water - Wets the sides of sand grains or other mineral material. This water cannot as a rule be collected by pumping, although it can be evaporated and/or used by the roots of plants. From the Latin *pellis* meaning little skin or film.

Perched ground water - Unconfined ground-water separated from the underlying main body of ground-water by unsaturated rock.

Perennial yield - The yield that can be sustained indefinitely without depleting or damaging the aquifer.

Phreatophytes - Plants growing in and around playas or other regions of high ground water. They can send a vertical root system to depths of several tens of feet and are good indicators of shallow water. Pickleweed, saltgrass, tamarisk, and saltcedar are typical phreatophytes.

Planimeter - An instrument for measuring the area of any plane figure by passing a tracer around the perimeter.

Playa - A term used in the southwestern U.S. for a dry, barren area in the lowest part of an undrained desert basin underlain by clay, silt, or sand, and commonly by soluble salts.

Pleistocene - Geologic time period during which a great deal of the world was covered with ice. It is commonly called the Ice Age. It began between 1 and 2 million years ago and ended about 8,000 years ago.

Pliocene - Geological time period preceding the Pleistocene. It began about 10 million years ago and ended when the Pleistocene began.

Pluvial - Pertaining to abundant rain, precipitation, and resultant geologic changes.

Sedimentary rocks - Derived by erosion and deposition from older rocks. They may be well consolidated if old enough, or loose as in the case of the superficial deposits of Indian Wells Valley.

Solute - A dissolved substance.

Specific capacity - The amount of water that can be obtained from a unit volume of rock or alluvium, under a unit change in hydraulic head.

Swale - Low-lying or depressed and often wet stretch of land.

Tautology - A circular argument; A is B, B is C, therefore, C is A.

Tectonic - Pertaining to the forces involved in building mountainous or in large scale distortion of the earth.

Transmissivity - Ability of a whole aquifer to transmit water. In hydrology this is the amount of water crossing a contour line of the water table, per linear foot, per day, per unit hydraulic gradient.

Transpiration - Water is removed from animals or plants to the surrounding air. Transpiration is analogous to evaporation from the soil or a water surface.

Tuffaceous - Rocks containing volcanic ash, which is called tuff. Tuff is different from tuffa, which is a chemically precipitated rock often found along the shores of desert lakes.

Underflow - Quantity of water that flows through the soil beneath a certain point.

Vapor pressure - Pressure of a substance's vapor over a flat surface of the substance. The pressure of water vapor at the boiling point is equal to the pressure of the surrounding air.

Volcanic rocks - Molten material discharged from the earth that later solidifies; includes lava, volcanic ash, tuff, basalt, rhyolite, pumice, obsidian, and so forth. Most types of volcanic rock can be found in and around Indian Wells Valley.

Xerophytes - Desert plants living on pellicular water in a zone a few inches to a foot deep. The roots spread laterally for distances many times the size of the plant.

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